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WATER QUALITY IN THE UPPER COLORADO RIVER BASIN AND ITS RELATION TO RECLAMATION PROJECTS

C. T. Wright

Public Health Service
Salt Lake City, Utah

1958

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By

C. T. Wright
Sanitary Engineer Director

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U S Department of Commerce
Springfield VA 22151

Department of Health, Education, and Welfare
Public Health Service
Salt Lake City, Utah

1958

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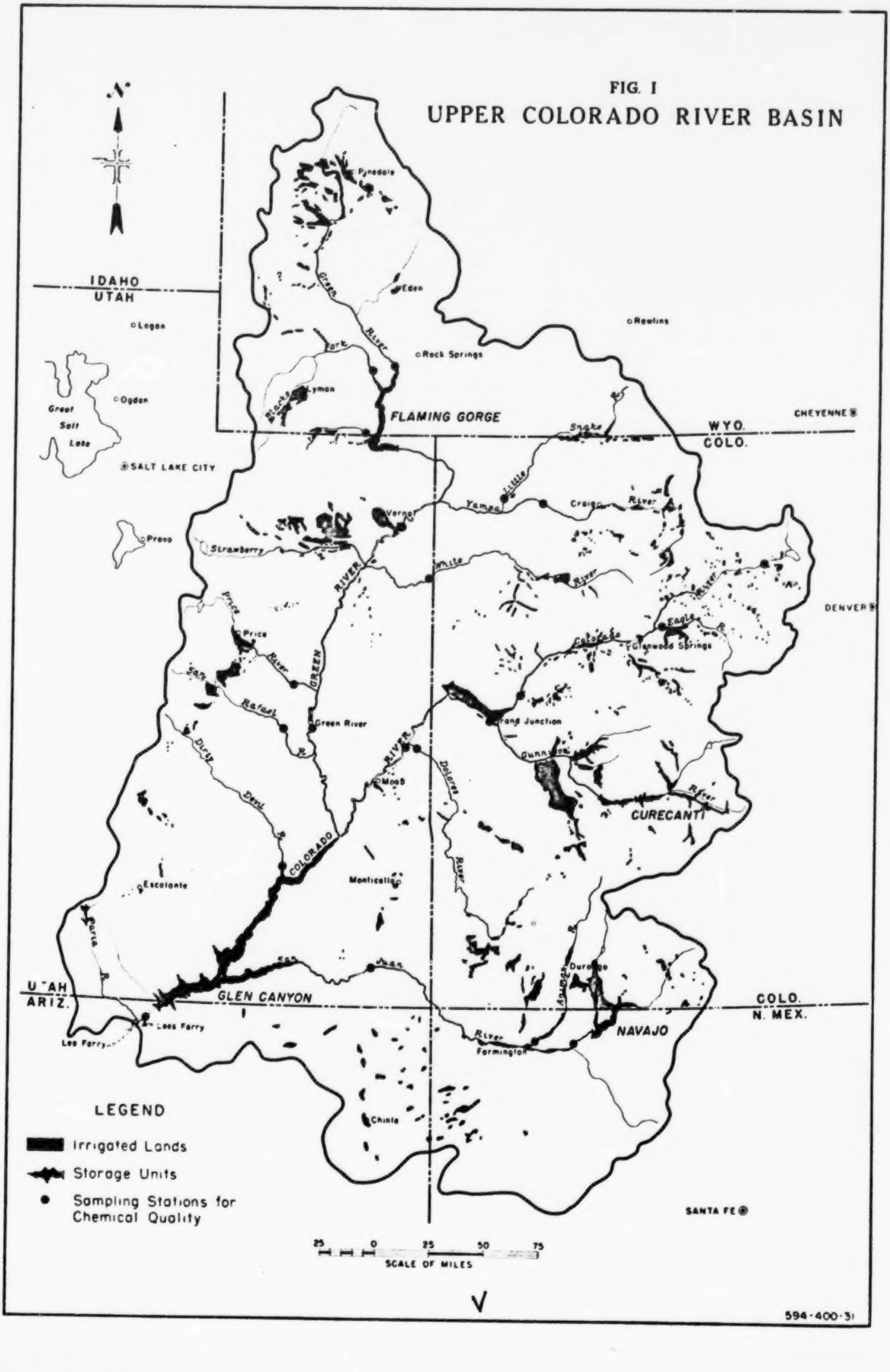


FIG. I

UPPER COLORADO RIVER BASIN

N
IDAHO
UTAH
WYO.
COLO.
UTAH
ARIZ.
COLO.
N. MEX.
Pinedale
Eden
Green River
Rawlins
Rock Springs
Logan
Ogden
Great Salt Lake
SALT LAKE CITY
Provo
Blacks Fork
Lyman
FLAMING GORGE
CHEYENNE
Snake R.
Little Snake
Yampa
Craig
River
Vernal
Strawberry
White River
DENVER
Eagle R.
Colorado
Glenwood Springs
Price
Price River
GREEN RIVER
San Rafael R.
Green River
Grand Junction
Gunnison
Gunnison River
CURECANTI
Dirty Devil R.
Moab
Dolores River
COLORADO RIVER
Monticello
Escalante
Paria R.
San Juan River
GLEN CANYON
Lees Ferry
Animas R.
Durango
NAVAJO
Formington
Chinle
SANTA FE
LEGEND
Irrigated Lands
Storage Units
Sampling Stations for Chemical Quality
25 0 25 50 75
SCALE OF MILES

594-400-31

WATER QUALITY IN THE UPPER COLORADO RIVER BASIN AND ITS RELATION TO RECLAMATION PROJECTS

Introduction

An ample supply of water of desirable quality for domestic, industrial, and agricultural purposes is essential for proper development and growth in the Upper Colorado River Basin. Since the future of this area will be largely dependent upon the conservation and proper utilization of the limited available water resources, many of the Federally sponsored water resource facilities must be multiple purpose in nature. In the development of irrigation projects, serious consideration should be given to the effects of these projects on municipal and industrial water supplies, pollution abatement, recreational development, and the conservation of fish and wildlife.

This study was made primarily for the purpose of assisting the Bureau of Reclamation in solving water quality problems being encountered in connection with the planning and operation of Reclamation projects. These problems include (1) the application of water quality requirements, (2) the effects of Reclamation projects on subsequent water use, and (3) the evaluation of chemical water quality data from sampling stations in the Upper Colorado River Basin.

In this study the following items were considered: the geologic, hydrologic, and other factors that influence water quality; the limiting water quality requirements for various uses; the nature, amount, and probable source of mineral constituents; the suitability of the water for domestic and industrial use; the effects of Glen Canyon and Flaming Gorge Reservoirs on water quality; and the need for future studies, research, and legislation.

The chemical quality section of this report was prepared primarily for the purpose of evaluating and interpreting the vast amount of data published in Geological Survey papers on chemical quality of surface waters in the Upper Colorado River Basin. (1)

Description of Upper Colorado River Basin (2)

The Colorado River originates in the snow-capped Rocky Mountains of north-central Colorado, flows nearly 1,400 miles southwest, and empties into the Gulf of California in Mexico far to the south. It is the second longest river in the United States outside the Mississippi River system. The Colorado River drains a vast area of 244,000 square miles, including 242,000 square miles in this country or one-twelfth the area of the Continental United States.

The Colorado River Compact provides principally for a division of the available water of the Colorado River system between the Upper Basin and Lower Basin at Lee Ferry, which is defined as a point on the Colorado River 1 mile below the mouth of the Paria River in northern Arizona. According to the compact, streamflows available for Upper Basin utilization will consist of the apportioned 7.5 million acre-feet per annum. The compact provides also that the states of the Upper Basin will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75 million acre-feet for any period of 10 consecutive years. A map of the Upper Colorado River Basin (Figure I) faces the introductory chapter of this report opposite page 1.

The Upper Colorado River Basin covers an area of 109,500 square miles, an area larger than New York, Pennsylvania, and New Jersey combined. The area is sparsely populated and according to estimates prepared from U.S. Census data, 298,700 people resided in the basin during 1950, which is equivalent to 2.72 persons per square mile. The upper or northern portion of the basin in Wyoming and Colorado is a mountainous plateau 5,000 to 8,000 feet in altitude. It is marked by broad rolling valleys, deep canyons, and intersecting mountain ranges. Many of the peaks in the mountain chains rise to more than 13,000 feet above sea level and many exceed 14,000 feet.

The main stream and its principal tributaries in Colorado flow for the most part in deep canyons. The Green River, primary tributary of the Colorado River, flows in similar canyons in Wyoming, Colorado, and Utah. The chief tributaries of the Green River, the Yampa and White Rivers from the east and the Duchesne, Price, and San Rafael Rivers from the west, flow through rolling hills and canyons.

The San Juan River, a large tributary of the Colorado River from the east, drains mountain slopes and plateaus in southwestern Colorado, northwestern New Mexico, and northern Arizona. It flows through a formidable canyon in southeastern Utah before joining the Colorado in Glen Canyon a short distance above Lee Ferry.

Geology and Soils (2)

Since the adjoining formations and soils have a direct bearing on water quality of the Colorado River and its tributaries, the following descriptions of the geology and soils in the Upper Basin are presented to assist the reader in obtaining a better understanding of subsequent comments on the problem of water quality.

Geology

Rocks of all ages from those of the Archean Age, the oldest known geological period, to the most recent alluvial deposits, including igneous, sedimentary, and metamorphic types, are found in the Upper Colorado River Basin. The Rocky Mountains which dominate the topography of this region are composed of granite, schists, gneisses, lava, and sharply folded sedimentary rocks. Many periods of deposition and erosion have played a part in the present structure of these mountains. Ancient seas settled in the basin, countless times depositing beds of limestone, sandstone, and shale.

During a relatively late geological period, called the Pleistocene or Glacial Age, glaciers occupied the higher watershed of all the mountains in Colorado, Wyoming, and Utah. The Rocky Mountains in Colorado, the Wind River Mountains in Wyoming, and the Uinta and Wasatch Mountains in Utah all have been materially affected topographically by these glaciers.

In contrast to the folded rocks of the mountains which fringe the basin, the plateau country of southwestern Wyoming, eastern Utah, and northern Arizona is composed principally of horizontal strata of sedimentary rocks. There exist also in the plateau country many formations of hard sandstone and limestone separated by softer shale.

Slow but constant elevation of the general land area has allowed the Colorado River and its tributaries to cut narrow deep canyons into the flat-topped mesas.

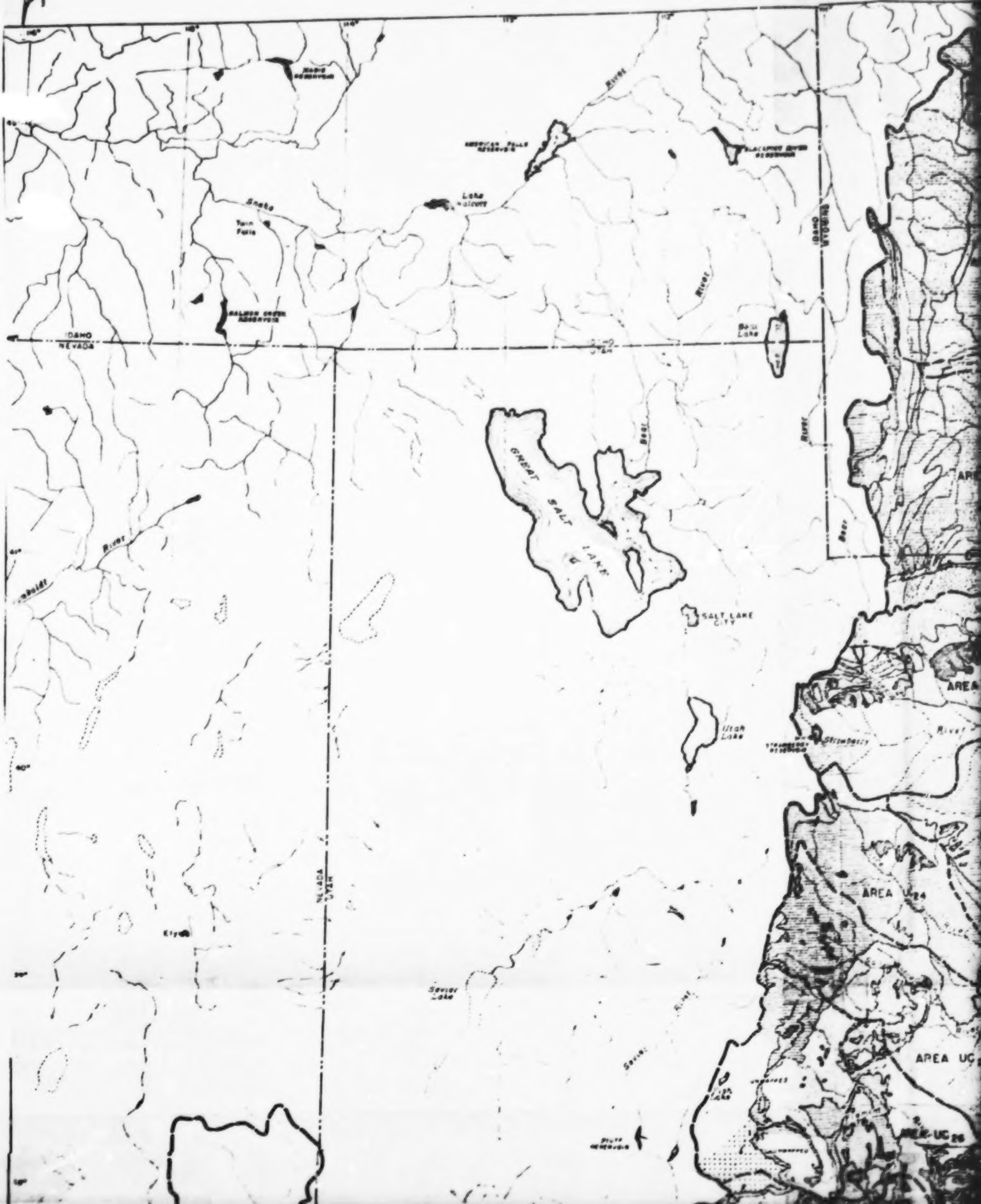
Soils

The entire upper basin is underlain with sandstone, limestone, and shales composing the parent rock from which the soil-forming material has been derived. Four types of soil are found: (1) alluvial soil made up from stream-deposited materials, (2) glacial soils in the form of glacial deposits or outwash plains derived partly from granites and other igneous material of the higher mountains, (3) residual soils formed in place by the weathering of surface rocks but altered in places through deposition from higher residual lands, and (4) aeolian or wind-deposited soils, appearing in a few places as sand dunes and other formations.

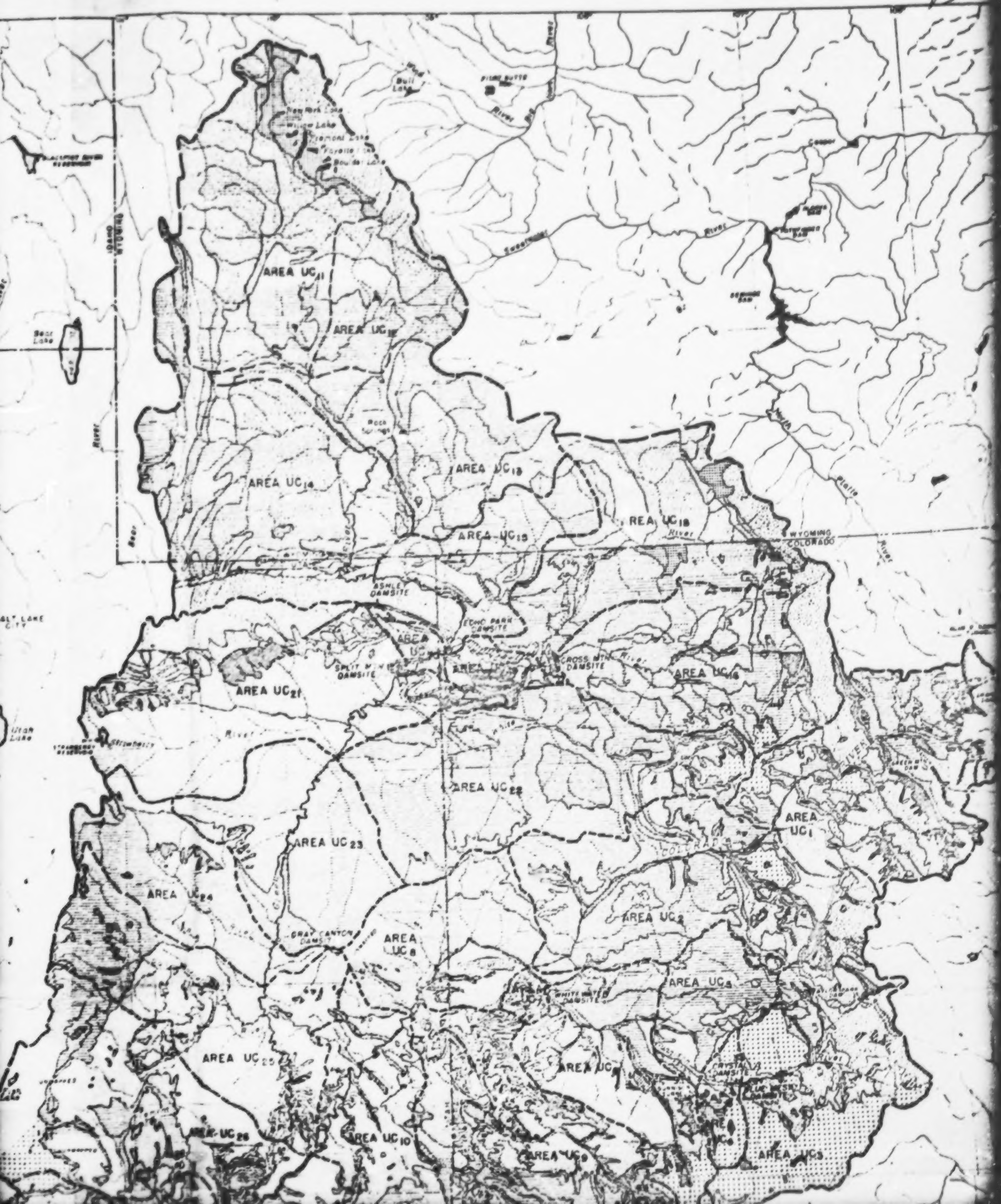
In the upper valleys, lands suitable to agricultural development are largely composed of alluvial soils and are confined to the bottom lands, terraces, and valley fills. These soils are high in organic matter and are inherently fertile. They are generally of sandy loam to loam in texture. Most of these soils have good natural drainage provided by light textured soil over gravelly subsoil and a moderate slope. With the exception of small localized areas the soils in the upper valleys are free from harmful accumulations of alkali.

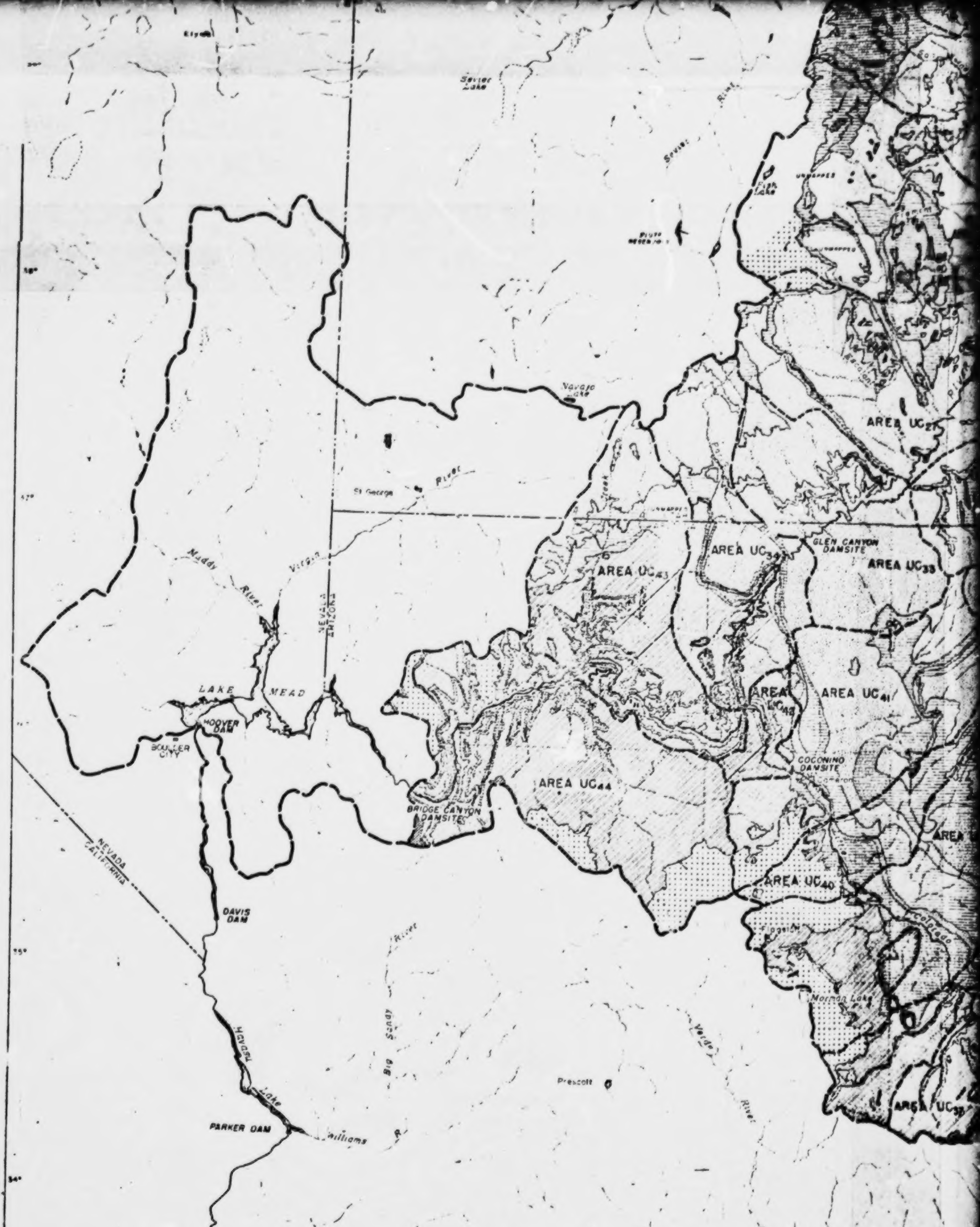
Mesas, plateaus, basin-like depressions caused through erosion, and narrow valleys along the various streams characterize the lower sections of the Upper Basin. The broader valleys and depressions that have been covered with alluvial soils are more suitable for cultivation where soil is of sufficient depth. Vast areas of residual soils are too shallow or too alkaline for agricultural development. Extensive drainage is often necessary in the lower valleys where irrigation is practiced.

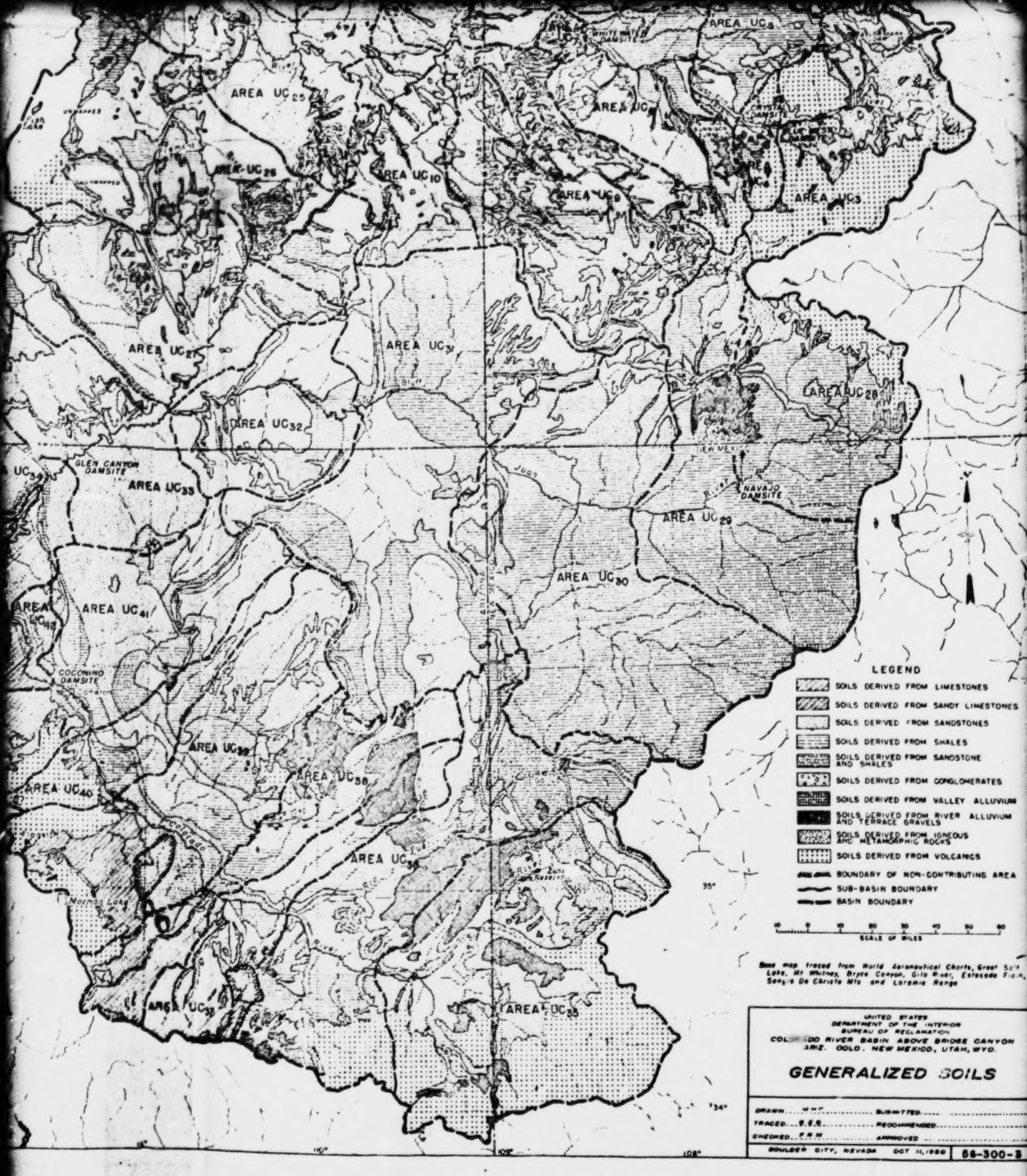
A


Snake
Twin Falls
Lake Walcott
River
American Falls Reservoir
Blackfoot River Reservoir
Salmon Creek Reservoir
IDAHO
NEVADA
IDAHO
UTAH
IDAHO
WYOMING
River
Bear Lake
Bear
River
Bear
GREAT SALT LAKE
SALT LAKE CITY
Utah Lake
Strawberry Reservoir
Strawberry
River
Humboldt
River
NEVADA
UTAH
Ely
Sevier Lake
Sevier River
Sevier
Piute Reservoir
AREA
AREA
AREA UC 24
AREA UC
AREA-UC 26

B


AREA UC11
AREA UC12
AREA UC13
AREA UC14
AREA UC15
AREA UC18
AREA UC16
AREA UC21
AREA UC22
AREA UC23
AREA UC24
AREA UC25
AREA UC26
AREA UC1
AREA UC2
AREA UC3
AREA UC4
AREA UC5
AREA UC6
AREA UC7
AREA UC8
AREA UC9
AREA UC10
AREA UC
New Fork Lake
Willow Lake
Fremont Lake
Boulder Lake
Bull Lake
Pilot Butte
Rock Springs
Bear Lake
Sweetwater
Casper
North Platte River
River
Bear River
ASHLEY DAMSITE
ECHO PARK DAMSITE
SPLIT MTN DAMSITE
CROSS MTN DAMSITE
GRAY CANYON DAMSITE
WHITEWATER DAMSITE
CRYSTAL DAMSITE
WYOMING
COLORADO
IDAHO
WYOMING
SALT LAKE CITY
Utah Lake
Strawberry Reservoir
White River
COLORADO RIVER


Ely
Sevier Lake
Sevier River
Piute Reservoir
Fish Lake
UNMAPPED
Escalante
River
AREA UC27
Navajo Lake
St George
Virgin River
Muddy River
Creek
NEVADA
ARIZONA
LAKE MEAD
HOOVER DAM
BOULDER CITY
AREA UC43
AREA UC34
GLEN CANYON DAMSITE
AREA UC33
AREA UC42
AREA UC41
COCONINO DAMSITE
Cameron
AREA UC44
BRIDGE CANYON DAMSITE
AREA UC40
Flagstaff
Colorado
Mormon Lake
AREA UC39
NEVADA
CALIFORNIA
DAVIS DAM
Havasu Lake
PARKER DAM
Williams R.
Big Sandy River
Prescott
Verde River
HORSESHOE DAM
38°
37°
35°
34°
115°
114°
113°
112°
111°


AREA UC8
WHITE WATER DAMSITE
AREA UC25
AREA UC7
CRYSTAL DAMSITE
BLUE MESA DAMSITE
AREA UC26
AREA UC10
AREA UC9
AREA UC5
AREA UC6
AREA UC27
AREA UC31
AREA UC28
AREA UC32
GLEN CANYON DAMSITE
UC34
AREA UC33
NEW MEXICO
NAVAJO DAMSITE
AREA UC29
AREA UC30
AREA UC41
AREA UC42
COCONINO DAMSITE
AREA UC39
AREA UC38
AREA UC40
Colorado
AREA UC36
Mormon Lake
AREA UC37
AREA UC35
35°
34°
LEGEND
SOILS DERIVED FROM LIMESTONES
SOILS DERIVED FROM SANDY LIMESTONES
SOILS DERIVED FROM SANDSTONES
SOILS DERIVED FROM SHALES
SOILS DERIVED FROM SANDSTONE AND SHALES
SOILS DERIVED FROM CONGLOMERATES
SOILS DERIVED FROM VALLEY ALLUVIUM
SOILS DERIVED FROM RIVER ALLUVIUM AND TERRACE GRAVELS
SOILS DERIVED FROM IGNEOUS AND METAMORPHIC ROCKS
SOILS DERIVED FROM VOLCANICS
BOUNDARY OF NON-CONTRIBUTING AREA
SUB-BASIN BOUNDARY
BASIN BOUNDARY
10 0 10 20 30 40 50 60
SCALE OF MILES

Base map traced from World Aeronautical Charts, Great Salt Lake, Mt Whitney, Bryce Canyon, Gila River, Estacado Plain, Sangre De Christo Mts and Laramie Range

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER BASIN ABOVE BRIDGE CANYON
ARIZ. COLO. NEW MEXICO, UTAH, WYO.

GENERALIZED SOILS

DRAWN.....W.H.F.......... SUBMITTED..........
TRACED...G.F.R.......... RECOMMENDED..........
CHECKED...F.R.M.......... APPROVED..........
BOULDER CITY, NEVADA OCT 11, 1950 58-300-3

D

The preceding generalized Soils Map, Drawing No. 56-300-3, shows the various types of soils that are encountered in the Upper Basin.

Limiting Water Quality Requirements

Chemical, physical, and bacteriological quality of water are generally the limiting factors in determining suitability of water for domestic, industrial, agricultural, and other purposes. The following is a list of the major beneficial uses of water in the Upper Colorado River Basin.

1. Domestic water supply
2. Industrial water supply (including cooling water)
3. Agricultural water supply (irrigation)
4. Water power
5. Stock and wildlife watering
6. Propagation of fish and other aquatic life
7. Recreation
8. Disposal of sewage and industrial wastes

Water with a wide range in chemical characteristics is generally encountered in the Upper Colorado River Basin, therefore, its suitability for domestic and industrial purposes varies to a considerable extent at various points in the basin.

Although reference will be made to various phases of water quality in subsequent comments, the greater portion of this report will be devoted to an analysis of the vast amount of data published by the Geological Survey on chemical quality.

Proper interpretation and evaluation of the data covering water quality and quantity collected by the Geological Survey and other agencies require a general knowledge of limiting water quality requirements for various uses. To aid in the interpretation of this material, water quality criteria for domestic, industrial, and irrigation water and for fish life and recreation are summarized in the following sections.

Domestic water

According to the Public Health Service Drinking Water Standards (3), a "water supply system includes the works and auxiliaries for collection, treatment, and distribution of the water from the source of supply to the free flowing outlet of the ultimate consumer."

In evaluating water quality criteria for domestic use, two conditions must be considered: (1) quality of the water at the source of supply, and (2) its quality as supplied to the ultimate consumer.

Bacterial Quality at Source of Supply

Many of the states have adopted raw water limits for the coliform bacterial content of waters to be used for domestic purposes. These guides have been patterned after U.S. Public Health Service recommendations appearing in "Public Health Bulletin No. 296, Manual of Recommended Sanitation Practice." (4) In the manual raw waters have been classified in the following groups with respect to the amount of treatment required to provide water that meets the Drinking Water Standards.

Group I--Water Requiring No Treatment.--This group is limited to underground waters not subject to any possibility of contamination and meeting in all respects the requirements of the P. H. S. Drinking Water Standards.

Group II--Waters Requiring Simple Chlorination.--This group includes both underground and surface waters subject to a low degree of contamination and meeting the requirements of the P. H. S. Drinking Water Standards in all respects except as to coliform bacterial content, which should average not more than 50 per 100 ml. in any month.

Group III--Waters Requiring Completed Rapid-Sand Filtration Treatment, or its Equivalent, Together with Continuous Postchlorination.--This group includes all waters requiring filtration treatment for turbidity and color removal; water of high or variable chlorine demand; and waters polluted by sewage to such an extent as to be inadmissible to groups I and II, but containing numbers of coliform bacteria averaging not more than 5,000 per 100 ml. in any one month and exceeding this number in not more than 20 percent of the samples examined in any one month.

Group IV--Waters Requiring Auxiliary Treatment[1] in Addition to Complete Filtration Treatment and Postchlorination.--This group includes waters meeting the requirements of Group III with respect to the limiting monthly average coliform numbers but showing numbers of coliform bacteria exceeding 5,000 per 100 ml. in more than 20 percent of the samples examined during any one month and not exceeding 20,000 per 100 ml. in more than 5 percent of the samples examined during any one month.

Since experience has demonstrated that adequately designed and well operated water treatment plants can successfully treat raw water with a coliform density in excess of 5,000 per 100 ml., consideration is being given to the revision of present permissible limits of coliform organisms in raw surface waters.

Drinking Water Standards(3)

The U.S. Public Health Service Drinking Water Standards (1946) have generally been accepted as the standards for all public water supplies in this country. These standards state in effect that water delivered to consumers shall be safe from a bacteriological standpoint and shall be clear, have no objectionable taste or odor, and shall not contain an excessive amount of soluble mineral substances nor excessive amounts of any chemicals employed in treatment.

---

[1] Auxiliary treatment referred to is presedimentation or prechlorination, or their equivalent, either separately or combined as may be necessary.

The Drinking Water Standards of particular interest in this evaluation are the limiting chemical requirements which are divided into mandatory requirements for certain substances and recommended upper limits for others.

Mandatory Limiting Requirements

1.	Lead	0.1	ppm
2.	Fluoride	1.5	"
3.	Arsenic	0.05	"
4.	Selenium	0.05	"
5.	Hexavalent chromium	0.05	"

Recommended Upper Limits

1.	Copper	3.0	ppm
2.	Iron and manganese together	0.3	"
3.	Magnesium	125	"
4.	Zinc	15	"
5.	Chlorides	250	"
6.	Sulfate	250	"
7.	Phenolic compounds, in terms of phenol	0.001	"
8.	Total or dissolved solids desirable or 1,000 if now other water is available	500	"

A further discussion of total or dissolved solids, sulfates, and hardness follows, inasmuch as these constituents exceed requirements for domestic and industrial water quite frequently at the sampling stations under consideration as compared to the other chemical substances which seldom exceed the above limits.

Total or Dissolved Solids.--In natural waters the dissolved solids consist mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates, and possibly nitrates of calcium, magnesium, sodium, and potassium, with traces of iron, manganese, and other substances. The mineral content of natural waters may be lowered artificially by dilution or raised by the addition of chemical wastes, dissolved salts, acids, alkalies, gas and oil well brines, or drainage water from irrigated land. Dissolved solids of about 1,000 ppm produce a taste to most people regardless of the combination of salts present.

Dissolved solids in industrial waters can cause foaming in boilers and interfere with clearness, color, or tastes of many finished products.

Sulfates.--Sulfate is present in most natural waters and it may be dissolved in relatively large quantities from beds of gypsum and shale.

Waters containing a high concentration of magnesium and sodium sulfate have a cathartic effect upon consumers. Sulfate in waters that contain much calcium and magnesium contributes to the formation of hard scale in steam boilers and affects the use of waters in other industrial processes.

The limit of 250 ppm for sulfates does not appear to be based on taste or physiological effects other than a laxative effect encountered by new users. Public water supplies with sulfate content above this limit are commonly used without adverse effects.

Wipple is quoted by Moore (5) to the effect that the taste thresholds of sulfate salts are as follows:

Sodium sulfate	200-500 ppm
Calcium sulfate	200-900 ppm
Magnesium sulfate	400-600 ppm

Sulfates cannot be removed from water by conventional methods of treatment.

Hardness.--Most natural waters dissolve various amounts of the common mineral compounds, particularly those including calcium and magnesium. It is the presence of these metals which causes water to be hard, the degree of hardness being directly proportioned to the concentration of the metal salts. Hardness is the characteristic of water that receives the most attention in industrial and domestic use. The term hardness is applied to the soap-neutralizing power of water. Soap will not cleanse nor lather until all of the hardness is precipitated as insoluble salts of the fatty acids. The detrimental effects of hardness include excessive soap and detergent consumption in homes and laundries, the formation of scum and curds in homes, laundries, and textile mills, the toughening of vegetables cooked in hard waters, and the formation of scale in boilers, water heaters, radiators, and pipes, with the resultant decrease in rate of heat transfer, possibility of boiler failure and loss of flow.

Water with less than 60 ppm of hardness is usually rated as soft and suitable for many purposes without further softening. Waters with hardness ranging from 60 to 120 ppm, although considered moderately hard, are not objectionable for domestic purposes. Waters with hardness ranging from 120 to 250 ppm are considered hard. The hardness of water of good quality should not exceed about 250 ppm. Water may be softened for municipal or industrial use by the cold lime-soda process, the cation exchange or zeolite process, and a combination of the lime-cation exchange processes. In the cold lime-soda process, the hardness is reduced by the use of either lime or lime-soda ash. In the cation-exchange process, the hardness is removed by an exchange of cations effected in passing the hard water through the softener units and then mixing the completely softened water with enough hard water to provide a mixed effluent of the desired composition. The average operating cost of 8 central states water softening plants during 1929-30 was $13.36 per million gallons for each 100 ppm of hardness removed (6).

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Table I
Water Quality Tolerances for Industrial Applications1/

Allowable limits in parts per million

Ca	Fe	Mn	Fe + Mn	SiO2	F	CO3	HCO3	OH	CaSO4	Na2SO4 to Na2SO3 ratio	General2/
	0.5	0.5	0.5								A, B
	0.2	0.2	0.2								C
				40		200	50	50		1 to 1	
				20		100	30	40	4	2 to 1	
				5		40	5	30		3 to 1	
00-200	0.1	0.1	0.1		1				100-200		C, D
00-500	0.1	0.1	0.1		1				200-500		C, D
	0.2	0.2	0.2								C
	0.2	0.2	0.2		1						C
	0.2	0.2	0.3		0.2						C
	0.2	0.2	0.2								
	0.5	0.5	0.5								A, B
	0.2	0.2	0.2								C
	0.2	0.2	0.2	10							C
	0.2	0.2	0.2								
	0.02	0.02	0.02								
	1.0	0.5	1.0								A
	0.2	0.1	0.2								
	0.1	0.05	0.1								
	0.1	0.05	0.1								B
	0.2	0.2	0.2								
	0.25	0.25									
	0.25	0.25	0.25								
	1.00	1.00	1.00								
	0.2	0.2	0.2								

Footnotes for Table I

1/ American Water Works Association--1950.

2/ A--No corrosiveness; B--No slime formation; C--Conformance to USPHS Drinking Water Standards necessary; D--NaCl 275 ppm.

3/ Waters with algae and hydrogen sulfide odors are most unsuitable for air conditioning.

4/ Some hardness desirable.

5/ Water for distilling must meet the same general requirement as for brewing (gin and spirits mashing water of light beer quality; whiskey mashing water of dark beer quality).

6/ Clear, odorless, sterile water for syrup and carbonization. Water consistent in character. Most high quality filtered municipal water not satisfactory for beverages.

7/ Hard candy requires pH of 7.0 or greater, as low value favors inversion of sucrose, causing sticky product.

8/ Control of corrosiveness is necessary as is also control of organisms, such as sulfur and iron bacteria, which tend to form slimes.

9/ $Ca(HCO_3)_2$ particularly troublesome. $Mg(HCO_3)_2$ tends to greenish color. CO_2 assists to prevent cracking. Sulfates and chlorides of Ca, Mg, Na should each be less than 300 ppm (white butts).

10/ Uniformity of composition and temperature desirable. Iron objectionable as cellulose absorbs iron from dilute solution. Manganese very objectionable, clogs pipelines and is oxidized to permanganate by chlorine, causing reddish color.

11/ Excessive iron, manganese or turbidity creates spots and discoloration in tanning hides and leather goods.

12/ Constant composition.

13/ Calcium, magnesium, iron, manganese, suspended matter, and soluble organic matter may be objectionable.

Irrigation water

The suitability of water for irrigation is generally evaluated in terms of total dissolved solids, percent sodium, and boron content. Other factors involved in agricultural use of irrigation water are boron sensitivity of the crops grown, volume of irrigation water used, drainage of the soil to be irrigated, and salinity of the soil.

The following tables give an accepted standard for irrigation water.

Permissible limits for electrical conductivity and percent sodium for several classes of irrigation water(8)

Classes of Water Rating	 Grade	Electrical conductivity EC x 106 at 25°C	Percent sodium
1	Excellent	250	20
2	Good	250 to 750	20 to 40
3	Permissible	750 to 2,000	40 to 60
4	Doubtful	2,000 to 3,000	60 to 80
5	Unsuitable	3,000	80

Permissible limits for boron of several classes of irrigation water in parts per million(7)

Classes of water Rating	 Grade	Sensitive crops (ppm)	Semitolerant crops (ppm)	Tolerant (ppm)
1	Excellent	0.33	0.67	100
2	Good	0.33 to 0.67	0.67 to 1.33	1.00 to 2.00
3	Permissible	0.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	Unsuitable	1.25	2.50	3.75

Irrigation waters in the range of 750 to 2,250 micromhos/cm, or about 475 to 1,500 ppm of dissolved solids are widely used, and satisfactory crop growth is obtained under good management and favorable drainage conditions. Saline conditions will develop, however, if leaching and drainage are inadequate. Use of waters with conductivity values above 2,250 micromhos/cm is the exception and very few instances can be cited where such waters have been successfully used. From the standpoint of total or dissolved solids, the upper limit for irrigation waters is much greater than the same requirement for drinking water and for most industrial water supplies.

Hardness in irrigation water in the form of calcium and magnesium sulfate is generally beneficial to irrigation inasmuch as these salts improve the physical condition of the soil by making it more permeable and workable for agricultural purposes. As a matter of fact calcium sulfate is recommended by soil scientists for the amelioration of true alkali soil conditions. Crops will tolerate these salts in much higher concentrations than the desirable upper limits for sulfates and hardness in water utilized for domestic purposes and many industrial uses.

Generally accepted bacteriological standards or requirements for irrigation waters have not been established because the relationship between the bacteriological quality of irrigation waters and the possibility of disease transmission through crops irrigated with sewage, sewage treatment plant effluents, or sewage polluted water has not been definitely established.

Fish life(9)

The establishment of water quality criteria for the propagation of fish life is a complicated problem and it is therefore difficult to establish exact numerical limiting values for the environmental factors involved.

The quality of the receiving water is particularly important in determining the effects of many wastes. Among the factors influencing the toxicity of pollutants in a particular receiving water are temperature, carbon dioxide, dissolved oxygen, hydrogen ion concentration, alkalinity, hardness, and dissolved materials. Other factors which may modify the toxicity of a waste are complexation, precipitation, oxidation, synergy, and antagonism.

In view of the many factors which may influence the effects of pollutants in different streams, numerical data which are to apply to extensive areas can be set only for temperature, D.O., and pH. With few exceptions, such as the insecticides and certain other materials, the approach would consist of bio-assays of the wastes in question. Water from the receiving stream taken from the area into which the waste is to be discharged would be used for dilution purposes. The characteristics of water that determine its suitability for fish life include:

1. Total dissolved solids. Concentrations up to 3,000 ppm can be tolerated by most fishes if the materials in solution are the relatively nontoxic earth metals and are physiologically balanced.

2. Hydrogen-ion concentration. In large areas pH values should not fall below 5 or exceed 9.5, but for good fish production 6.5 to 8.5 is a desirable range.

3. Dissolved oxygen. For a well rounded fish population D.O. levels should not be below 5 ppm. If a coarse fish population is desired, minimum levels may fall to 2 ppm.

4. Carbon dioxide. Concentrations under 30 ppm in the absence of other adverse factors will have no harmful effects on most species.

5. Temperature. In the northern portion of the country, peak temperatures for warm water fishes should not exceed 93° F, while

in the southern portion of the country temperatures should not exceed 96° F. While trout can stand peak temperatures of 80°F to 83°F for short periods, best production is obtained in streams having summer temperatures of 60°F to 68°F.

6. Toxic wastes. Allowable concentrations of toxic complex wastes for each stream or situation should be determined by means of bio-assays and safe dilutions estimated by the use of application factors.

Recreation

As with irrigation water, factual information and epidemiological evidence as to what constitutes a safe coliform density in water used for swimming or other recreational uses are lacking. Evaluation of the significance of coliform densities in natural bathing places is complicated by the natural coliform population of the water; i.e., coliform-type bacteria washed from the hills by rains and melting snow.

The Joint Committee on Bathing Places of the Conference of State Sanitary Engineers and the Engineering Section of the American Public Health Association (10) suggested that the final determination as to the suitability of outdoor bathing places should be determined largely by a sanitary survey of the area using bacteriological information as a guide only. Many coliform standards have been established by regulatory authorities, but these standards have generally been based upon the natural coliform densities and reasonably attainable objectives. Some areas of the country are reported to be able to meet bacterial standards for natural surface waters with maximum limits of coliform indexes of not more than 240 to 500 per 100 ml. Such excellent quality is, of course, greatly to be desired. However, experience indicates that other sections of the country, especially those located in more densely populated areas and among cultivated lands, cannot maintain such conditions. Waters showing a concentration of most probable numbers of coliform organisms of less than approximately 1,000/100 ml. are considered in most areas to be fairly acceptable for bathing unless the sanitary survey discloses immediate dangers from human sewage and pollution. It must be admitted, however, that bathing beaches where the content of coliform organisms runs as high as 2,400/100 ml. on the basis of most probable numbers, or sometimes even higher, have been used without reported evidence of illness. The limit of 2,400/100 ml. is still employed as a criterion of acceptability in some states.

Water used for swimming should also be free from obnoxious floating or suspended solids and from objectionable color and odors. The water should be free of pathogenic organisms and substances which are toxic to humans.

Deterioration of Water Quality from Pollution and Irrigation Return Flow

Water pollution

Pollution may be defined as contamination, or other alteration of the physical, chemical, or biological properties, of water, or such discharge of any liquid, gaseous, or solid substance into water as will create a nuisance or render such waters harmful or detrimental or injurious to public health, safety, or welfare, or to domestic, commercial, industrial, recreational, or other legitimate beneficial uses, or to livestock, wild animals, birds, fish, or other aquatic life.

Surface water pollution from sewage and industrial wastes in the sparsely settled watershed of the Upper Basin is not as pronounced as in the more populous river basins. The waters of the basin, however, receive enormous quantities of pollution from natural sources in the form of sediment and mineral salts. Pollution from these sources originates in virtually every part of the basin with the exception of extreme headwater areas, primarily because the desert type soils in the arid and semi-arid portions of the basin are subject to serious erosion during periods of runoff. These problems will become more acute with population and industrial growth and further depletion of streamflow.

When all or a greater share of the streamflow has been appropriated for irrigation and other purposes, there is generally a lack of dilution water to maintain water quality during reservoir filling and irrigation diversion. Under these conditions the streamflow below reservoirs and major irrigation diversions gradually increases, primarily from return flow, raw sewage, industrial wastes, and treatment plant effluents. As the downstream flow increases, it is usually diverted for various uses although it may be of questionable quality for domestic, industrial, and agricultural purposes.

With the exception of extreme headwater areas, most of the waters in the Upper Basin fall in the Group III category, which requires complete rapid sand filtration or its equivalent and continuous postchlorination for domestic water supplies.

The objective of State Water Pollution Control authorities is to restrict impairment of water quality by domestic, industrial, and other wastes so that the water will not be adversely or unreasonably affected for various beneficial uses.

The concentration of many pollutants in water depends primarily upon the amount of polluting substances and the volume of diluting water available in the stream. The dilution available is one of the most important factors governing the extent and seriousness of pollution. These problems generally require individual analysis and study which involve an accurate determination of pollution and a precise evaluation of dilution water required prior to initiating control measures. Water pollution abatement generally involves the effects of self-purification of organic wastes, together with adequate treatment of wastes prior to discharge and subsequent dilution in the receiving stream. In some cases small volumes of domestic and industrial wastes can be eliminated at the source by retention and evaporation in lagoons or stabilization ponds.

Dilution water also plays an important role in the self-purification of streams inasmuch as the rate of purification is largely dependent upon the velocity of flow, the character of organic matter reaching the stream, presence of available oxygen in the diluting water to oxidize the organic matter, the rate or aeration by dilution and wind action, sedimentation, and temperature.

The following is an example of the dilution water required to maintain quality for domestic water supplies when the effects of self-purification are insignificant. Complete treatment of domestic wastes and subsequent dilution are essential to provide water that meets the coliform content of 5,000 per 100 ml. for Group III waters requiring complete treatment. Estimates indicate that effluent from a sewage treatment plant where complete treatment and postchlorination have been provided would require dilution water of desirable quality in the ratio of about 8 to 1 by volume to meet this requirement. If self-purification of a stream below points of waste disposal is significant, however, the volume of dilution water required could be reduced accordingly.

Effects of irrigation return flow on surface water supplies (11)

All natural waters contain some dissolved mineral matter. The quantity of this material depends upon the formations through which the water passes and the length of time it has been in contact with this material. Some streams are fed by both surface runoff and underground water from springs and seeps. Such streams reflect the chemical character of their concentrated underground sources during dry periods and are more dilute during periods of heavy rainfall. The concentration of dissolved solids in a river water is frequently increased by drainage from mines or oil fields, by the addition of industrial or municipal wastes, and by return flow from irrigated lands. Since irrigation return flow in the Upper Colorado River Basin contributes to the increase in concentration of dissolved mineral matter, a further discussion of this problem appears appropriate.

Considerable variation in the effects of irrigation return flow on water quality is to be expected. The factors involved include: size of irrigated areas, number of times water is used, properties of soils, age of irrigation project, nature of aquifers, rainfall, dilution, temperature, irrigation practices, and storage reservoirs.

A substantial portion of the water diverted for irrigation is consumed by evaporation and transpiration. Consumptive use of irrigation water is equivalent to evapo-transpiration, and it has been defined as "the water used by plants in transpiration and growth, plus moisture evaporated from the surface of the soil and vegetation." Annual consumptive use of irrigation water, exclusive of effective precipitation in the Upper Basin, averages about 1.5 acre-feet per acre of irrigated land. Consumptive use accounts for roughly two-thirds of all irrigation water used. The remaining third generally finds its way back to the stream channel from which it was diverted and is commonly referred to as "return flow." The amount of water withdrawn for irrigation varies over a wide range. Not all of this water is available for crop production inasmuch as there is a significant loss between the point of diversion and its use for irrigation. From 20 to 60 percent of the water diverted may reappear as return flow although, as previously stated, a general average value for return flow is approximately 33 percent.

Maintenance of a favorable salt balance is an important aspect of irrigation practice. According to Scofield (12), the salt balance is "the relationship of salt input to salt output." When the input of mineral salts is less than the output, the salt balance is favorable. The object of irrigation project drainage is to remove not only surplus water, but also as much harmful mineral matter as is brought in by the water applied to the land.

Little of the total mineral content of the water is taken up by plants. Consequently, as evaporation and transpiration occur, there is an appreciable concentration of salts. Most of the original mineral matter is then contained in a much smaller volume of return flow. Repeated salt concentration by evaporation and transpiration, together with leaching of saline soils, can result in considerable increase in concentration of minerals in the receiving stream. The general tendency in the Upper Basin, as the water is used and reused for irrigation, is in the direction of a significant increase in the concentration of total dissolved mineral solids, with attendant increments in hardness and sulfate content.

Available information indicates that the concentration of total dissolved solids in return flow in the absence of salt accumulation from groundwater is increased from about 2 to 10 times the concentration of salts in the applied irrigation water. This increase in the salt concentration is the result of continual moisture extraction by plants and evaporation (13). The volume of water used and the number of times it is reused are contributing factors to the variation in concentration of dissolved mineral matter in return flows. Where considerable amounts of salts are carried in solution by return flows, consideration should be given to the amount of less saline water required for dilution to maintain satisfactory water quality for downstream users. Provision should be made to meet this requirement in estimating storage needs.

Data covering quality and quantity of return flows from existing Reclamation projects is lacking for use in evaluating the effects of return flows on water quality below proposed projects.

State water pollution control agencies consider the high mineral concentration of return flows from irrigated areas as a source of stream pollution along with industrial and municipal wastes, and in some cases standards or requirements have been adopted to control excessive mineral concentration of waters used for domestic and industrial purposes.

It is apparent from the foregoing that studies on the use of water for irrigation should include the effect of irrigation return flow on surface and groundwater supplies. Complete reports on the results of these studies should be included in Bureau of Reclamation project reports, especially when return flows may affect the quality of downstream municipal and industrial water supplies. These problems should also be discussed with State water pollution control agencies during project planning to resolve the problems that may be created by the discharge of return flows.

Water Use

Irrigation presently accounts for the greatest use of water in the Upper Colorado River Basin. Much of the irrigated acreage produces pasture grasses and hay and serves as a home base for livestock grazing on the vast areas of range and forest land. Some of the irrigated lands at lower elevations, however, are devoted to more intensive farming with vegetables and fruits as the chief crops.

The following figures on irrigated acreage and stream depletion in the Upper Basin are closely related to problems pertaining to water use, quality and return flows:

1.	Estimated total acreage available for irrigation in 1956	1,342,000 acres
2.	Estimated annual average depletion from existing developments and developments authorized prior to 1949	2,550,000 acre-feet

Annual man-made depletions in the Upper Colorado River Basin from existing developments and developments authorized prior to 1949, the year the Upper Colorado River Compact became effective, are estimated to average about 2,550,000 acre-feet. A number of years will be required for full development of projects authorized prior to 1949. The 2,550,000-acre-foot depletion is therefore considered as applying to fiscal year 1963, when initial operation of the storage project is scheduled and is also referred to as the present depletion. On the basis of the annual depletion of 2,550,000 acre-feet, the Upper Basin is utilizing only about one-third of the consumptive use apportioned to it by the Colorado River Compact. Man-made depletions include water utilized for irrigation, transmountain diversion, and water lost by evaporation from existing storage units. During 1956 transmountain diversion of water from the Basin accounted for about 530,000 acre-feet which amounted to about 21 percent of the total depletion.

As a basis for evaluating the Colorado River Storage project and participating projects, a projection was made of future stream depletions estimated to occur in the Upper Basin during the 100-year period from fiscal year 1963 through fiscal year 2062. It was estimated that the depletions by 2062 would total about 6,191,000 acre-feet annually, consisting of 2,550,000 acre-feet from existing developments, 691,000 acre-feet from evaporation from the authorized storage units, and 2,950,000 acre-feet from new projects including the authorized participating projects and other future Federal and non-Federal developments (14).

Of the total acreage referred to in item 1 above, Bureau of Reclamation projects accounted for an acreage of approximately 320,118 or about 24 percent during 1956. Information regarding existing Bureau of Reclamation projects in the Upper Basin, together with the irrigable acreage and irrigated acreage for 1956, is listed in Table II on the following page.

Data Presented and Period Covered by Study

The chemical analyses and discharge records presented in this report were obtained from U.S. Geological Survey water supply papers. These results are tabulated by water years in Geological Survey papers, and the same procedure was followed in preparing Figures II to XXIV, pages 39 to 61. Each water year starts on October 1 and ends on September 30. Quality records are limited to the sampling stations shown on the map of the Upper Colorado River Basin which faces the introductory chapter of this report. Further information regarding the sampling stations and the duration of the sampling periods covered is given in Table III.

Samples for chemical analysis were collected daily at the stations listed in Table III which are located at or near points on streams where gaging stations are maintained for measurement of water discharge. Most of the analyses were made on 10-day composites of daily samples collected over the period listed in column three of the foregoing table. Three composite samples were usually prepared each month by mixing together equal volumes of daily samples collected from the first to the tenth, from the eleventh to the twentieth, and during the remainder of the month.

The mineral constituents and physical properties reported in the tables of analyses appearing in Geological Survey papers include those that have a practical bearing on the value of waters for most purposes. The analyses generally include results of silicon, iron, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, boron, dissolved solids, hardness, and pH.

Data presented

The chemical constituents presented in the following tables and figures are limited to results that generally exceed requirements for

Table II
Bureau of Reclamation Operating Projects
Upper Colorado River Basin

Project	Location		Construction completed	Irrigable Acreage in 1956	Irrigated Acreage in 1956
	State	Nearest town			
Eden	Wyo.	Eden, Wyo.	Uncompleted	10,070	8,894
Fruitgrowers Dam	Colo.	Delta, Colo.	1940	2,662	2,080
Grand Valley	Colo.	Grand Junction, Colo.	1917	42,495	36,601
Mancos	Colo.	Durango, Colo.	1948	8,761	7,672
Moon Lake	Utah	Duchesne, Utah	1940	75,256	58,802
Paonia	Colo.	Paonia, Colo.	1952	11,653	9,008
Pine River	Colo.	Durango, Colo.	1941	41,193	37,337
Pine River (Indian Project)	Colo.	Durango, Colo.	1941	9,666	9,666
Sanpete	Utah	Ephraim, Utah	1937&38	13,663	12,368
Scofield	Utah	Helper, Utah	1945	15,609	14,409
Uncompahgre	Colo.	Montrose, Colo.	1922	89,090	75,478
Total				320,118	272,315

Note: Figures in Columns 5 and 6 obtained from "Statistical Appendix to 1956 Crop Report and Related Data." U.S. Dept. of Interior.

Table III
Upper Colorado River Sampling Stations(1) Included in Study

Location of sampling stations	Date sampling started	Period of record covered in tables and charts (water years)
Colorado River at Hot Sulphur Springs, Colo.	April 1947	1947-1955
Eagle River at Gypsum, Colo.	April 1947	1947-1955
Colorado River near Glenwood Springs, Colo.	Oct. 1941	1946-1955
Colorado River near Cameo, Colorado	Oct. 1933	1946-1955
Gunnison River near Grand Junction, Colo.	Oct. 1931	1946-1955
Dolores River near Cisco, Utah	Mar. 1951	1951-1956
Colorado River near Cisco, Utah	Oct. 1928	1946-1955
Green River at Green River, Wyo.	May 1951	1951-1955
Blacks Fork at Green River, Wyo.	Mar. 1951	1951-1955
Henrys Fork at Linwood, Utah	Mar. 1951	1951-1955
Yampa River near Maybell, Colo.	Dec. 1950	1951-1955
Little Snake River near Lily, Colo.	Dec. 1950	1951-1955
Green River at Jensen, Utah	June 1947	1947-1952
Dropped	Sept. 1952	
White River near Watson, Utah	Dec. 1950	1951-1955
Price River at Woodside, Utah	Feb. 1948	1948-1955
Green River at Green River, Utah	Oct. 1928	1946-1955
San Rafael River near Green River, Utah	Jan. 1947	1948-1955
Re-established	Jan. 1947	
Dirty Devil River near Hite, Utah	July 1948	1948-1954
Colorado River at Hite, Utah	Oct. 1950	1951-1955
San Juan River near Blanco, N. Mex.	10-1 1945	1946-1954
Animas River at Farmington, N. Mex.	6-1 1940	1946-1954
San Juan River near Bluff, Utah	Feb. 1927	1946-1955
Colorado River at Lees Ferry, Ariz.	10-1 1947	1948-1954

Note: Beginning with the uppermost station on the main stem or tributary, all sampling stations appearing in Table III are listed as they occur in sequence in downstream order.

Although the average flow at Lees Ferry, Ariz., for the 10-year period (1946-1955) covered by this study is below the average flow for the 60-year period 1896 to 1955, it covers a period that includes average, unusually high, and low flow conditions. The results presented in Figures II to XXIV therefore represent a wide range in flow conditions.

domestic and industrial purposes most frequently. These results include dissolved solids, sulfates, and total hardness for all stations, together with magnesium for the Price, San Rafael, and Dirty Devil Rivers, and chlorides for the Dolores and Dirty Devil Rivers. All of the remaining chemical constituents published by the Geological Survey for the 1946-1955 period, other than those referred to under the above heading, are within the limits of the Drinking Water Standards. Therefore limited reference will be made to these chemical constituents.

Figures II to XXIV, pages 39 to 61, show the relationship between discharge in cubic feet per second and dissolved solids, sulfates, total hardness, chlorides, and magnesium in parts per million for the sampling stations and periods listed in Table III. The desirable upper limits for potable water of the above constituents are shown by the heavy dashed horizontal line drawn through the graphs where the ordinate scales of the graphs permitted the insertion of the dashed line.

The results presented in Figures II to XXIV have been summarized in Table VI, page 38. The table also presents information on the size of the drainage area above each gaging station and the irrigated acreage and percentage of the irrigated acreage on the watershed above each gaging station.

Factors Affecting Chemical Quality

Surface waters generally have a wide range in chemical quality which is attributed to the following factors: geology, soil, streamflow, topography, pollution from domestic and industrial wastes, and agricultural uses. Rain and snow, which are relatively pure and devoid of mineral matter when formed, start to dissolve material from the soil as soon as they come in contact with the earth's surface.

In the mountainous regions that are underlain by granite, schists, gneisses, lava, and folded sedimentary rocks, the water is generally of excellent quality for most uses, and the mineral content is composed mostly of calcium and magnesium. In the plateau country below the foothills many hard sandstone and limestone formations separated by softer shales are encountered. Where the Colorado River drains an area of erodible sandstone and shales, the river water is much more concentrated and the mineral content consists largely of sodium and sulfate. Sulfate is present in most natural waters, and it is generally dissolved in relatively large quantities from beds of gypsum and shale.

Runoff and streamflow influence the chemical characteristics of water in a drainage area. The quantity of dissolved mineral matter in a natural water depends upon the velocity of flow or the length of time the water has been in contact with the formations through which it passes. In the mountainous areas of the Upper Colorado River Basin rain and snow-melt have little opportunity to dissolve material before reaching the stream and flowing to lower areas. The slower runoff and streamflow on the flatter areas are more favorable for solution of salts, especially where ground water from springs, seeps, and return flows contributes to streamflow.

The chemical quality of water in a flowing stream varies from day to day in relation to the discharge. Generally the low, or base, flow of the stream is sustained by ground water inflow that leaches the soluble minerals of rocks and soil particles before reaching the stream. At high stages and during floods, the salt concentration of the base flow is diluted by snowmelt and surface runoff. Figures II to XXIV show that the maximum concentration of salts occurs during low flows and conversely the minimum concentration occurs during high flows.

Table IV, page 24, shows the relationship of discharge, dissolved solids, and suspended sediment at key Upper Basin locations and at Lees Ferry for the period 1948-1955, inclusive. It is apparent from these figures that the combined flow for the Colorado River near Cisco, Utah, and the Green River at Green River, Utah, which approximates 80 percent of the total, contributes about 80 percent of the dissolved solids and only 36 percent of the suspended sediment at Lees Ferry. In the lower portion of the basin, however, the combined flow from the San Juan River near Bluff, Utah, and downstream flows below Cisco, Green River, and Bluff, Utah, provide only 18 percent of the total flow, but contribute 20 percent of the dissolved solids and 64 percent of the suspended sediment at Lees Ferry.

Factors Affecting Chemical Quality at Various Sampling Stations

Colorado River (Grand Division)

The Colorado River rises among lofty peaks in the northwest portion of Rocky Mountain Natural Park and flows southwest to the Green River, a distance of 420 river miles. The area drained by this section of the river, called the Grand Division, consists of 26,500 square miles, 89 percent of which is in Colorado and 11 percent in Utah. On the western slope of the Continental Divide where the Colorado River originates, rugged mountains and high plateaus are encountered where the river and its numerous tributaries have become deeply entrenched in steep rugged canyons and relatively narrow valleys.

Colorado River at Hot Sulphur Springs, Colo.

From its headwaters to the first sampling station at Hot Sulphur Springs, the Colorado River traverses about 30 miles and drains an area of 782 square miles. Only 13,000 acres or about 2.6 percent of this area is irrigated. The results shown in Figure II and the

Table IV
Relationship of Discharge, Dissolved Solids, and Suspended Sediment at Key Upper Basin Locations and Totals at Lees Ferry - Water Years 1948-1955 Inclusive

	Drainage area in sq. miles	Avg. annual discharge in acre-feet	Percent of stream flow at Lees Ferry	Avg. annual dissolved solids in tons	Percent of dissolved solids at Lees Ferry	Avg. annual suspended sediment in tons	Percent of suspended sediment at Lees Ferry
Colorado River near Cisco, Utah	24,100	4,789,000	43.0	4,031,200	48.1	8,621,004	12.4
Green River at Green River, Utah	40,600	4,371,000	39.3	2,686,782	32.0	16,546,287	23.9
San Juan River near Bluff, Utah	23,000	1,482,840	13.3	830,000	9.9	19,025,431	27.4
Downstream from Cisco, Green River, and Bluff, Utah gaging stations	20,200	482,700	4.4	840,478	10.0	25,279,227	36.3
Colorado River at Lees Ferry	107,900	11,125,620	100.0	8,388,460	100.0	69,471,949	100.0

unplotted U.S. Geological Survey records for the period of study show that the water consistently meets the chemical requirements of the Drinking Water Standards and it is therefore considered satisfactory for domestic, industrial, and agricultural purposes. The area drained is composed mostly of granite, schists, gneisses, and sedimentary rocks and soils made up from these materials. Runoff from an area of this type fed largely by melting snow is naturally low in mineral content and of satisfactory chemical quality.

Eagle River at Gypsum, Colo.

The sampling station at Gypsum, Colo., is located on the Eagle River, a tributary that enters the Colorado River from the east about 18 miles above Glenwood Springs, Colo. The watershed consists of 957 square miles, 15,000 acres or 2.5 percent of which is irrigated. This is the first station on the Upper Colorado River where an appreciable increase in the mineral content was noted. Although the stream originates near the Continental Divide, it drains an area consisting of soils which have been largely derived from erodible sandstones, shales, and limestones, with sandstone formations predominating. These formations are apparently responsible for the marked increase in mineral content which exceeds desirable limits for domestic and industrial purposes during periods of low flow.

Colorado River near Glenwood Springs, Colo.

The Glenwood Springs station located about 140 miles below the headwaters receives flow from an area of 4,560 square miles. About 70,000 acres or 2.4 percent of this area is irrigated. Although the mineral content of the water at this point is substantially greater than that noted at Hot Sulphur Springs, the increase is apparently due to the high concentration of salts from tributary inflow. As a matter of fact the concentration of salts from the Eagle River is much greater than that noted at the Glenwood Springs sampling station. Although some deterioration of water quality is encountered at Glenwood Springs, the water is still considered satisfactory for domestic and agricultural purposes and many industrial uses.

Colorado River near Cameo, Colo.

The Cameo station, located about 75 miles below Glenwood Springs, receives flow from an area of 8,060 square miles. About 160,000 acres or 3.1 percent of this area is irrigated. Although the irrigated acreage on the watershed between the Cameo and Glenwood Springs sampling stations shows an increase of 90,000 acres, the increase in mineral content in this stretch of the river is limited. Refer to figures IV and V. The water generally meets the chemical requirements of the Drinking Water Standards and is considered satisfactory for domestic and agricultural purposes and many industrial uses.

Gunnison River near Grand Junction, Colo.

The Gunnison River and its tributaries, including the North Fork and Uncompahgre River, drain an area of 8,020 square miles, 238,000 acres or 4.6 percent of which is irrigated. This area has the highest percentage of irrigated acreage in the Upper Colorado River Basin, with the exception of the Henrys Fork area in Wyoming and Utah. Analyses of samples collected from the Gunnison River at the Gunnison Diversion tunnel of the Uncompahgre project, about 90 miles above the mouth of the river, show that the water above this point is of excellent chemical quality. This is attributed to the fact that this area is generally composed of soils derived from granite, schists, gneisses, and volcanic deposits. A great deal of this area supports forests and mountain meadows. Below the tunnel the inflow is highly mineralized from return flows and natural accretions. The drainage area below the tunnel is composed of soils derived largely from erodible shale and sandstone together with alluvium in the stream valleys. Water in the lower reaches of the Gunnison River is unsatisfactory for domestic and industrial purposes during periods of low flow which occur during the late summer and winter months.

Dolores River near Cisco, Utah

The Dolores River flows into the Colorado River from the southeast about midway between Grand Junction, Colo., and the mouth of the Green River. Although only 36,000 acres or about 1.3 percent of the drainage area is irrigated, the water at this station is highly mineralized. The mineralization is largely attributed to the soil cover of the drainage area, which is generally derived from erodible shale, sandstone, and silt. Unusually high concentrations of dissolved solids, sulfates, chlorides, and hardness are encountered at this station during periods of low flow when the water is considered unsatisfactory for domestic purposes and many industrial uses. The watersheds of the Dolores and Dirty Devil Rivers are the only areas covered by this study that contribute chlorides from extensive salt beds in concentrations that consistently exceed Public Health Service Drinking Water Standards during periods of low flows.

Colorado River near Cisco, Utah

The station near Cisco, Utah, is located just below the mouth of the Dolores River about midway between Grand Junction, Colo., and the mouth of the Green River. The drainage area above this station consists of 24,100 square miles, 530,000 acres or 3.4 percent of which is irrigated. In the 70-mile stretch between Cameo, Colo., and the Cisco station, a substantial increase in mineral content is encountered which is largely attributed to inflow from the Gunnison and Dolores Rivers and return flow from the 70,000-acre Grand Valley project located in the vicinity of Grand Junction. Although the mineralization from the Gunnison and Dolores Rivers is diluted in the Colorado River, the water at Cisco is still of questionable chemical quality for domestic and industrial purposes during periods of low flow. Table IV shows that of the totals at Lees Ferry the Colorado River at Cisco contributed 43 percent of the flow, 48 percent of the dissolved solids, and 12.4 percent of the suspended sediment for the period 1948-1955, inclusive.

Colorado River (Green Division)

The Green River Basin is rimmed by snow-covered peaks and wooded upland slopes in the Wind River Mountains. These are flanked with fertile grass-covered valleys which give way to dry and eroded badlands and deserts. The Green River drains 45,000 square miles in Wyoming, Utah, and Colorado in its meandering length of 730 miles between its origin and its confluence with the Colorado River. Its drainage area is 70 percent larger than that of the Colorado above their junction. Its average annual contribution to the Colorado River, however, is only 44 percent of the combined flows of the two streams at their confluence.

Green River near Green River, Wyo.

From its headwaters to the first sampling station near Green River, Wyo., the Green River travels about 190 miles and drains an area of 10,000 square miles. Only 150,000 acres or about 2.3 percent of this area is irrigated. The Green River and its tributaries emerge from canyons relatively clear and pure but increase in mineral content, especially in late summer when return flows from irrigation are high. Runoff from raw shale beds along La Barge, Fontenelle, and Big Sandy Creek carries a fairly high salt concentration. Results of analyses based on Bureau of Reclamation records show that water at the Fontenelle Dam site, located about 50 miles above Green River, Wyo., is of excellent chemical quality, and it is therefore considered satisfactory for domestic, industrial, and agricultural purposes. Between La Barge and Green River, the Green River drains an area consisting of soils derived primarily from sandstone, shale, and alluvial deposits in the river bottoms. Although these formations are responsible for a substantial increase in mineral content below Fontenelle, the water at Green River is still satisfactory for domestic purposes and most industrial uses. Since limited irrigation is carried on in this area, the major share of the increase in salt content is the result of natural accretions from the soils in the watershed.

Blacks Fork near Green River, Wyo.

This station is located on Blacks Fork which flows into the Green River from the west about 25 miles below Green River, Wyo. The drainage area above this station consists of 3,670 square miles of which 74,000 acres or 3.2 percent is irrigated. This is the first station on the Upper Green River where an appreciable increase in mineral content was noted. Blacks Fork drains an area of soils derived from erodible sandstone, shale, clay, and limestone. Drainage from this area together with return flows from an area where repeated use is made of irrigation water apparently accounts for the high mineral content noted. During periods of low flow, water at this station is of questionable quality for domestic and industrial purposes.

Yampa and Little Snake Rivers

The Yampa River, located largely in northwestern Colorado, drains the eastern area of the Green River Basin and discharges into the Green River about 30 miles south of the Colorado-Wyoming borderline. The Maybell, Colo., sampling station receives flow from an area of 3,410 square miles. About 2.7 percent of the drainage area is irrigated. Although the river above Maybell drains soils largely derived from sandstone and shale, the chemical quality of the water is satisfactory for domestic, industrial, and agricultural purposes. This is attributed to the fact that the mountainous terrain is responsible for rapid runoff and previous leaching of the softer shales.

The Little Snake River flows into the Yampa below the Cross Mountain Dam site. It drains an area of 3,730 square miles, about 0.9 percent of which is irrigated. The river drains soils largely derived from sandstone, shale, and alluvium in the river valley. Although the Little Snake River has a higher mineral content than the Yampa at Maybell, it is still considered of fair quality for domestic and industrial purposes.

Green River at Jensen, Utah

This station is located on the Green River at Jensen, about 15 miles below the proposed Split Mountain Dam site. The watershed above this point covers an area of about 25,260 square miles, of which 331,000 acres or approximately 2 percent is irrigated. With the exception of the high concentration of salts from Blacks and Henrys Forks, the chemical quality at sampling stations on the Green River above Jensen is satisfactory for most purposes. This is reflected in the results covering the Jensen sampling station. Although there has been an increase in the chemical constituents at this station, the water is considered satisfactory for domestic purposes and most industrial uses except during periods of extremely low flow.

White River near Watson, Utah

The White River flows into the Green River from the east and the drainage area above Watson, Utah, has an acreage of 4,020 square miles. About 30,000 acres or 1.2 percent of the drainage area is irrigated. Although the salt content of the water at Watson is high during periods of low flow, the water is considered of fair quality for domestic purposes and most industrial uses.

Price River at Woodside, Utah

The Price River flows into the Green River from the west about 20 miles above Green River, Utah. The watershed above Woodside covers an area of 1,500 square miles. About 18,000 acres or 1.9 percent of this area is irrigated. The mineral content of Price River at Woodside is higher than that at any sampling station on the Upper Colorado River, and the water is considered unsuitable for domestic, industrial, and agricultural purposes. The high mineralization is due largely to the nature of the adjoining soil formations, and lack of soil cover in the foothill or plains areas. The soils are derived primarily from erodible shale, sandstone, and silt beds. The upper reaches of the Price River drain an area composed of tertiary and cretaceous rocks interspersed with formations of conglomerate and terrace gravels that give way to shales and sandstones in the vicinity of Helper, Utah. The nature of the soils and the lack of soil cover in the plains area are largely responsible for the unusually high mineral content at Woodside. The sampling stations on the Price, San Rafael, and Dirty Devil Rivers are the only stations on the Upper Colorado River where the content of magnesium consistently exceeds the Drinking Water Standards. Although results of chemical analyses on the upper reaches are lacking, the river water above Helper, Utah, is considered satisfactory for most purposes. The effect of return flow on the overall chemical quality of the Price River at Woodside is considered of minor significance.

Green River at Green River, Utah

This station is located on Green River about 65 river miles above the confluence of the Green and Colorado Rivers. The drainage area above this station includes 40,600 square miles, of which 551,000 acres or 2.1 percent is irrigated. Regardless of the high concentration of salts contributed by Blacks Fork, Henrys Fork, the Price River, and other tributaries that flow into the Green River from the west, the chemical quality of the water at Green River is considered fair to poor for domestic purposes and most industrial uses.

Table IV shows that of the totals at Lees Ferry for the period 1948-1955, inclusive, the flow of Green River at Green River, Utah, accounted for about 39 percent of the flow, 32 percent of the dissolved solids, and 24 percent of the suspended sediment.

San Rafael River near Green River, Utah

The San Rafael River flows into the Green River from the west about 25 river miles below Green River, Utah. Above the sampling station near Green River the river drains an area of 1,690 square miles, of which 36,000 acres or 3.3 percent is irrigated. From the standpoint of chemical quality the water at this station is in about the same range as the Price River water at Woodside. The usually high mineral content at this station makes it unsuitable for domestic, industrial, and agricultural purposes. The high mineral concentration is derived primarily from watershed drainage that passes through and over barren soils derived largely from shale and sandstone. Although a fairly large portion of the drainage area is irrigated, return flows contribute only a minor share of the salts encountered.

Colorado River (San Juan Division)

The Colorado River from the mouth of the Green River to Lees Ferry is commonly referred to as the San Juan Division. Deeply entrenched in a plateau area, the Colorado River meanders southwestward for 220 miles from the mouth of the Green River to Lees Ferry. This section of the river, together with its tributaries, drains 39,000 square miles. Forty-three percent of this area is in Utah, 25 percent in New Mexico, 17 percent in Arizona, and 15 percent in Colorado.

Dirty Devil River near Hite, Utah

The Dirty Devil River flows into the Colorado River from the west about 40 river miles below the mouth of the Green River. The chemical quality of the water at this point is similar to that encountered at the sampling stations on the Price and San Rafael Rivers, and the water is considered unsatisfactory for domestic, industrial, and agricultural purposes. The soil formations on the watershed are similar to those encountered in the Price and San Rafael drainage areas.

Colorado River at Hite, Utah

The sampling station on the Colorado River at Hite, Utah, is located about 45 miles below the mouth of the Green River. Above this station the river drains an area of 76,600 square miles, of which 1,149,000 acres or 2.3 percent is irrigated. The water at this station quite frequently exceeds desirable limits for potable water and it is therefore considered of fair to poor quality for domestic and industrial purposes.

San Juan River at Blanco, N. Mex.

The station on the San Juan River at Blanco, N. Mex., is located about 19 miles below the Navajo Dam site and 24 miles above Farmington, N. Mex. Above the station the river drains an area of 3,560 square miles, of which 2.3 percent is irrigated. During the period under consideration the water consistently met the chemical requirements of the Drinking Water Standards and it is therefore considered satisfactory for domestic, industrial, and agricultural purposes.

Animas River at Farmington

The Animas River drains an area of 1,360 square miles, of which 3.5 percent is irrigated. The upper reaches of the watershed are composed largely of igneous rocks that give way to soils derived principally from sandstone and shale, with sandstone predominating. Although the water is quite hard at the station at Farmington, it is otherwise satisfactory for domestic purposes and many industrial uses.

San Juan River at Bluff

The San Juan River drains an area of 23,000 square miles above Bluff. About 1.3 percent of this area is irrigated. The barren watershed below Blanco is made up of soils derived primarily from extensive formations of erodible shale and sandstone. During the greater part of each year, the chemical quality of the water at Bluff exceeds desirable limits, and the water is therefore considered poor for domestic and industrial purposes. However, during periods of high flow, which generally occur in the spring and summer months, the water is of satisfactory chemical quality for most uses.

Table IV shows that at Lees Ferry during the period 1948-1955, inclusive, the San Juan River near Bluff, Utah, contributes 4.4 percent of the total flow, 10 percent of the total dissolved solids, and 36.3 percent of the total suspended sediment.

Colorado River at Lees Ferry, Ariz.

The sampling station on the Colorado River at Lees Ferry, Ariz., is located about 1.3 miles above Lee Ferry, the dividing point between the Upper and Lower Colorado River Basins. This is the final station on the Upper Colorado River and the results of chemical analyses at this point reflect the cumulative effect of salts contributed from the entire basin. The Colorado River at Lees Ferry drains an area of 107,900 square miles. About 1,342,000 acres or approximately 2 percent of this area is irrigated. During the greater part of each year the chemical quality of the water is questionable for domestic and industrial purposes, and the water is classed as poor for such purposes. The chemical quality of the water fluctuates with the flow of the river; i.e., during periods of high flow the chemical quality is satisfactory and conversely the quality is poor during low flows. Water quality at this station will be altered considerably following completion of Glen Canyon Dam and Reservoir. The effects of holdover reservoir storage are discussed more fully under a subsequent heading on this subject.

Classification of Colorado River Water as a Source of Supply for Domestic Purposes

The above information regarding classification of Colorado River water at various sampling stations from the standpoint of chemical quality for domestic purposes has been summarized in Table V. Although water from tributary inflow from the Gunnison, Dolores, Price, San Rafael, and Dirty Devil Rivers and Blacks and Henrys Forks is classed as unsatisfactory at the sampling stations, the chemical quality of the water in the headwater areas is generally satisfactory for domestic, industrial, and agricultural purposes.

Effects of Flaming Gorge and Glen Canyon Reservoirs on Water Quality

Glen Canyon Reservoir and Dam to be located 16 miles above Lee Ferry will create more initial reservoir storage capacity than all other

Table V

Classification of Colorado River Water as a Source of Supply for Domestic Purposes

Sampling Stations	Chemical Quality				
	Excellent	Good	Fair	Poor	Unsuitable
Colorado River at Hot Sulphur Springs, Colo.	X				
Eagle River at Gypsum, Colo.			X		
Colorado River near Glenwood Springs, Colo.		X			
Colorado River near Cameo, Colorado		X			
Gunnison River near Grand Junction, Colo.					X
Dolores River near Cisco, Utah					X
Colorado River near Cisco, Utah				X	
Green River near Green River, Wyo.		X			
Black's Fork near Green River, Wyo.					X
Henry's Fork at Linwood, Utah					X
Yampa River near Maybell, Colo.	X				
Little Snake River near Lily, Colo.			X		
Green River at Jensen, Utah			X		
White River near Watson, Utah			X		
Price River at Woodside, Utah					X
Green River at Green River, Utah			X		
San Rafael River near Green River					X
Dirty Devil River near Hite, Utah					X
Colorado River at Hite, Utah				X	
San Juan River near Blanco, N Mex.		X			
Animas River at Farmington, N. Mex.			X		
San Juan River near Bluff, Utah				X	
Colorado River at Lees Ferry, Ariz.				X	

presently authorized units of the Colorado River Storage project combined. Flaming Gorge Reservoir and Dam to be located on the Green River 32 miles below the Utah-Wyoming border will provide the largest capacity of the authorized units next to the Glen Canyon unit. Since the reservoirs will be used primarily for the purpose of providing conservation storage, river regulation, power generation, and sediment retention, their effect on water quality will be significant. The following information regarding Glen Canyon and Flaming Gorge units has been presented to assist the reader in evaluating subsequent comments.

Reservoir	Dam height (feet above streambed)	Capacity (acre-feet) Active	Inactive	Total
Glen Canyon	580	21,505,000	6,535,000	28,040,000
Flaming Gorge	440	3,530,000	260,000	3,790,000

The natural flow of the Colorado River is quite variable both from month to month and from year to year. For example over 65 percent of the annual discharge at Lees Ferry usually occurs during the 4 months of spring runoff, April through July. Flows during this period, largely derived from melting snows, are generally of excellent quality. The flows of the river during the remaining 8 months are generally below the monthly average. The wide range in flow and dissolved salts in the Colorado River and its major tributaries is illustrated by the material presented in Figures II to XXIV, inclusive.

Dilution during spring runoff and prolonged storage and sedimentation in the Glen Canyon and Flaming Gorge Reservoirs will provide water at the reservoir outlet works which will be practically free from sediment and which will have fairly uniform chemical characteristics throughout the year. The concentration of mineral salts due to evaporation and the solution of salts from the reservoir surroundings during storage will be offset to some extent by precipitation of the dissolved solids as calcium carbonate. According to Dr. C. S. Howard of the Geological Survey, over 6.3 percent of the dissolved solids entering Lake Mead have been precipitated as calcium carbonate. Similar conditions will undoubtedly prevail at Flaming Gorge and Glen Canyon Reservoirs. There will also be a marked reduction of the bacterial content of the reservoir water from the effects of self-purification and the natural death rate of bacteria during storage.

Beneficial effects of storage and dilution in project reservoirs have been demonstrated by the following results of samples collected above and below Lake Mead for the water years 1951 and 1952.

Chemical Analyses in Parts per Million

Sampling stations	Water year	Dissolved solids		Total hardness		Sulfates	
		Max.	Min.	Max.	Min.	Max.	Min.
Colorado River near Grand Canyon, Ariz., above Lake Mead	1951	1,320	348	668	196	785	83
Colorado River below Hoover Dam	1951	692	625	340	299	275	235
Colorado River near Grand Canyon, Ariz.	1952	1,490	326	760	218	758	66
Colorado River below Hoover Dam	1952	706	524	344	268	295	248

The results of substances listed in the table vary over a wide range for the station above Lake Mead as compared to results below the reservoir, where they are fairly uniform throughout the year and close to desirable limits for downstream purposes. This condition will undoubtedly prevail in the vicinity of Flaming Gorge and Glen Canyon Reservoirs. The water discharged at the outlet works should, therefore, be of more desirable quality for domestic and many industrial purposes than water direct from the river prior to storage.

Summary and Conclusions

Since chemical requirements for domestic and industrial water supplies are much more rigid than similar requirements for irrigation water, planners of irrigation projects should keep this relationship in mind when irrigation projects are to be located above sources of water supply for domestic and industrial purposes.

Surface water pollution from sewage and industrial wastes in the Upper Basin is not pronounced, and it is generally limited to areas below communities and industrial developments. The waters of the basin, however, receive enormous quantities of pollution from natural sources in the form of sediment and mineral salts. Available information indicates that the major share of salts that reach the Colorado River come from natural decomposition and leaching of this material from adjoining geological formations. Depletion of streamflow by irrigation in the Upper Basin increased the concentration of dissolved solids at Lees Ferry during 1948-55 by an estimated 14.6 percent. Since Bureau of Reclamation projects accounted for about 24 percent of the total irrigated acreage in the Upper Basin during this period, the dissolved solids concentration contributed by Bureau projects amounted to about 3.5 percent of the total at Lees Ferry. The average annual historical flow at Lees Ferry during 1948-55 was about 11,126,000 acre-feet. Since this flow was below normal, the estimated increase in dissolved solids at Lees Ferry was higher than would be encountered during a period similar to 1914-45 when the flow at Lees Ferry averaged about 13,763,300* acre-feet.

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*Estimated by Engineering Advisory Committee to Upper Colorado River Basin Compact Commission.

Figures II to XXIV, inclusive, show that the mineral concentration in the Colorado River approaches or exceeds certain chemical requirements of the Drinking Water Standards. A substantial increase in the chemical constituents from various sources and by water depletion would make the water in some areas unsuitable for domestic purposes and many industrial uses.

The most critical area from the standpoint of potential pollution generally occurs below irrigation reservoirs and major irrigation diversions, when all or a greater share of the streamflow is utilized for agricultural and other purposes. Lack of dilution water of satisfactory quality from irrigation reservoirs or other sources and the subsequent increase in return flow from irrigated areas generally account for a substantial increase in mineral concentration in a stream. Maintenance of a live stream below irrigation projects is therefore desirable to provide adequate dilution to maintain water quality for subsequent use. Maintenance of minimum flow can be accomplished in some cases by releasing water directly from reservoirs or through powerplants.

With existing legislation, the Bureau of Reclamation is not in a position to provide storage in Reclamation reservoirs for public health purposes without reimbursement unless such allocation is authorized to be nonreimbursable by special or new legislation. Deterioration of water quality that may be caused by proposed Reclamation projects should be discussed with the State agencies involved during the early stages of project planning in an effort to solve these problems prior to project development.

Other factors that contribute to the overall mineral or salt concentration at Lees Ferry include reservoir evaporation, transmountain diversions, and the leaching of salts from irrigated land to maintain a positive salt balance. The concentration from other than transmountain diversion is limited inasmuch as (1) the concentration of mineral salts from reservoir evaporation is partially offset by precipitation, chiefly of calcium and silica; and (2) the fact that leaching of excess salt from irrigated areas is generally limited to the early stages of project operation. The irrigated areas generally become stabilized after the excess salts are removed with irrigation return flow.

Recommendations

It appears from the foregoing that the following procedures, studies, and research should be initiated and the proposed legislation enacted to assist in solving some of the problems being encountered on Reclamation projects.

1. Study effects of irrigation return flow on the quality of water for domestic and industrical use and the disposal of sewage or industrial waste effluents from projects now in operation.

2. Initiate research studies to develop methods for determining the quality of irrigation return flow in advance of project construction.

3. Include in engineering studies a complete report on the effects of return flow from the standpoint of chemical quality on subsequent water use.

4. Establish a sufficient number of sampling stations at sites for proposed projects to provide data for a valid estimate of the chemical quality of return flow.

5. In cooperation with State regulatory agencies, develop uniform water quality requirements to supplement available requirements that can be utilized in preparing criteria for estimating the amount of storage that will be required in Reclamation reservoirs to maintain minimum flows for public health purposes.

6. Include estimates of water quality and simulated flows below proposed reservoirs and irrigated areas in the water supply appendices for use in determining minimum flow requirements at key points below projects.

7. Furnish Public Health Service Regional Consultants with copies of the water supply appendices, together with reports on projects on which public health comments are desired.

8. Support legislation which provides for the inclusion of storage in reservoir projects without reimbursement to maintain low flows downstream in order to meet minimum flow requirements for public health purposes.

Note. The Public Health Service of the Department of Health, Education, and Welfare is in agreement with the public health aspects of the legislation referred to.

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Sampling stations	Drainage area in sq. miles above gaging station	Irrigated acreage above sampling station (1956)	% irrigated acreage on watershed (1956)	Sampling period
Colo. R. at Hot Sulphur Springs, Colo.	782	13,000	2.6	1947-55
Eagle R. at Gypsum, Colo.	957	15,000	2.5	1947-55
Colo. R. near Glenwood Springs, Colo.	4,560	70,000	2.4	1946-55
Colo. R. near Cameo, Colo.	8,060	160,000	3.1	1946-55
Gunnison R. near Grand Junction, Colo.	8,020	238,000	4.6	1946-55
Dolores R. near Cisco, Utah	4,400	36,000	1.3	1951-55
Colo. R. near Cisco, Utah	24,100	530,000	3.4	1946-55
Green R. near Green River, Wyo.	10,000	150,000	2.3	1951-55
Blacks Fork near Green River, Wyo.	3,670	74,000	3.2	1951-55
Henrys Fork at Linwood, Utah	531	21,000	6.2	1951-55
Yampa R. near Maybell, Colo.	3,410	65,000	2.7	1951-55
Little Snake R. near Lily, Colo.	3,730	21,000	0.9	1951-55
Green R. at Jensen, Utah	25,260	331,000	2.0	1947-52
White R. near Watson, Utah	4,020	30,000	1.2	1951-55
Price R. at Woodside, Utah	1,500	18,000	1.9	1948-55
Green R. at Green River, Utah	40,600	551,000	2.1	1946-55
San Rafael R. near Green River, Utah	1,690	36,000	3.3	1948-55
Dirty Devil R. near Hite, Utah		15,074		1948-54
Colo. R. at Hite, Utah	76,600	1,149,000	2.3	1949-55
San Juan R. near Blanco, N. Mex.	3,560	52,000	2.3	1946-54
Animas R. at Farmington, N. Mex.	1,360	30,000	3.5	1946-54
San Juan R. near Bluff, Utah	23,000	190,000	1.3	1946-55
Colo. R. at Lees Ferry, Ariz.	107,900	1,342,000	2.0	1948-55

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TABLE VI
Summary of Water Quality Data for the Upper Colorado River Basin
Period (water years 1946-1955)
Chemical constituents in parts per million

ri- ed s- e r- i 5)	Sampling period	Mean annual discharge in acre-feet	Dissolved solids				Total hardness			
			Max.	Min.	Mean	% samples exceeding 500 ppm.	Max.	Min.	Mean	% samples exceeding 250 ppm.
	1947-55	270,863	123	38	78	0.0%	77	20	47	0.0%
	1947-55	426,788	1,370	106	511	63.0%	970	73	311	68.7%
	1946-55	1,706,990	2,030	113	391	14.3%	1,480	85	183	4.5%
	1946-55	2,858,800	946	172	590	71.6%	376	106	250	62.3%
	1946-55	1,585,650	2,380	214	1,042	84.1%	1,160	143	559	84.3%
	1951-55	486,000	4,720	173	1,676	86.9%	1,690	120	454	81.6%
	1946-55	4,842,500	1,850	208	993	80.5%	886	131	454	82.4%
	1951-55	1,128,000	760	159	398	31.0%	412	114	238	44.6%
	1951-55	238,090	4,600	298	1,105	83.9%	1,980	48	506	84.5%
	1951-55	49,468	2,550	323	1,118	92.9%	1,530	208	708	97.7%
	1951-55	907,380	498	72	248	0.0%	238	45	142	0.0%
	1951-55	340,660	1,750	116	466	46.6%	1,340	66	200	35.2%
	1947-52	3,802,830	867	161	432	41.0%	494	110	254	41.1%
	1951-55	473,340	1,450	230	552	74.7%	1,410	133	286	78.0%
	1948-55	129,381	8,220	592	3,682	100.0%	3,010	353	1,431	100.0%
	1946-55	4,392,100	1,070	229	635	71.1%	592	146	310	73.9%
	1948-55	104,907	5,650	541	2,987	100.0%	2,280	330	1,305	100.0%
	1948-54		6,780	851	2,182	100.0%	2,860	435	1,212	100.0%
	1949-55	8,952,330	1,990	251	851	81.7%	1,080	155	435	77.8%
	1946-54	731,800	1,030	80	238	00.6%	680	53	137	1.3%
	1946-54	561,722	854	121	466	45.6%	448	90	278	65.5%
	1946-55	1,421,530	1,570	152	652	70.7%	731	104	348	76.4%
	1948-55	11,125,870	1,370	233	802	82.9%	662	148	418	75.5%

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r Colorado River Basin
-1955)
per million

solids		Total hardness				Sulfates			
Mean	% samples exceeding 500 ppm.	Max.	Min.	Mean	% samples exceeding 250 ppm.	Max.	Min.	Mean	% samples exceeding 250 ppm.
78	0.0%	77	20	47	0.0%	12	2.5	6	0.0%
511	63.0%	970	73	311	68.7%	784	23	195	38.6%
391	14.3%	1,480	85	183	4.5%	1,290	19	87	0.7%
590	71.6%	376	106	250	62.3%	231	29	142	0.0%
1,042	84.1%	1,160	143	559	84.3%	1,300	21	574	79.1%
1,676	86.9%	1,690	120	454	81.6%	1,690	68	323	70.2%
993	80.5%	886	131	454	82.4%	1,050	54	411	75.3%
398	31.0%	412	114	238	44.6%	365	34	170	15.9%
1,105	83.9%	1,980	48	506	84.5%	2,240	53	624	61.9%
1,118	92.9%	1,530	208	708	97.7%	1,530	95	574	89.8%
248	0.0%	238	45	142	0.0%	147	8.7	62	0.0%
466	46.6%	1,340	66	200	35.2%	1,420	15	160	35.2%
432	41.0%	494	110	254	41.1%	419	36	178	9.7%
552	74.7%	1,410	133	286	78.0%	2,160	48	175	10.9%
3,682	100.0%	3,010	353	1,431	100.0%	5,310	245	2,398	100.0%
635	71.1%	592	146	310	73.9%	444	48	215	60.7%
2,987	100.0%	2,280	330	1,305	100.0%	3,640	235	1,863	81.9%
2,182	100.0%	2,860	435	1,212	100.0%	2,750	361	1,193	100.0%
851	81.7%	1,080	155	435	77.8%	1,150	63	387	75.0%
238	00.6%	680	53	137	1.3%	517	11	75	1.1%
466	45.6%	448	90	278	65.5%	377	34	189	18.9%
652	70.7%	731	104	348	76.4%	868	41	351	74.0%
802	82.9%	662	148	418	75.5%	701	67	380	75.5%

C

Figure II

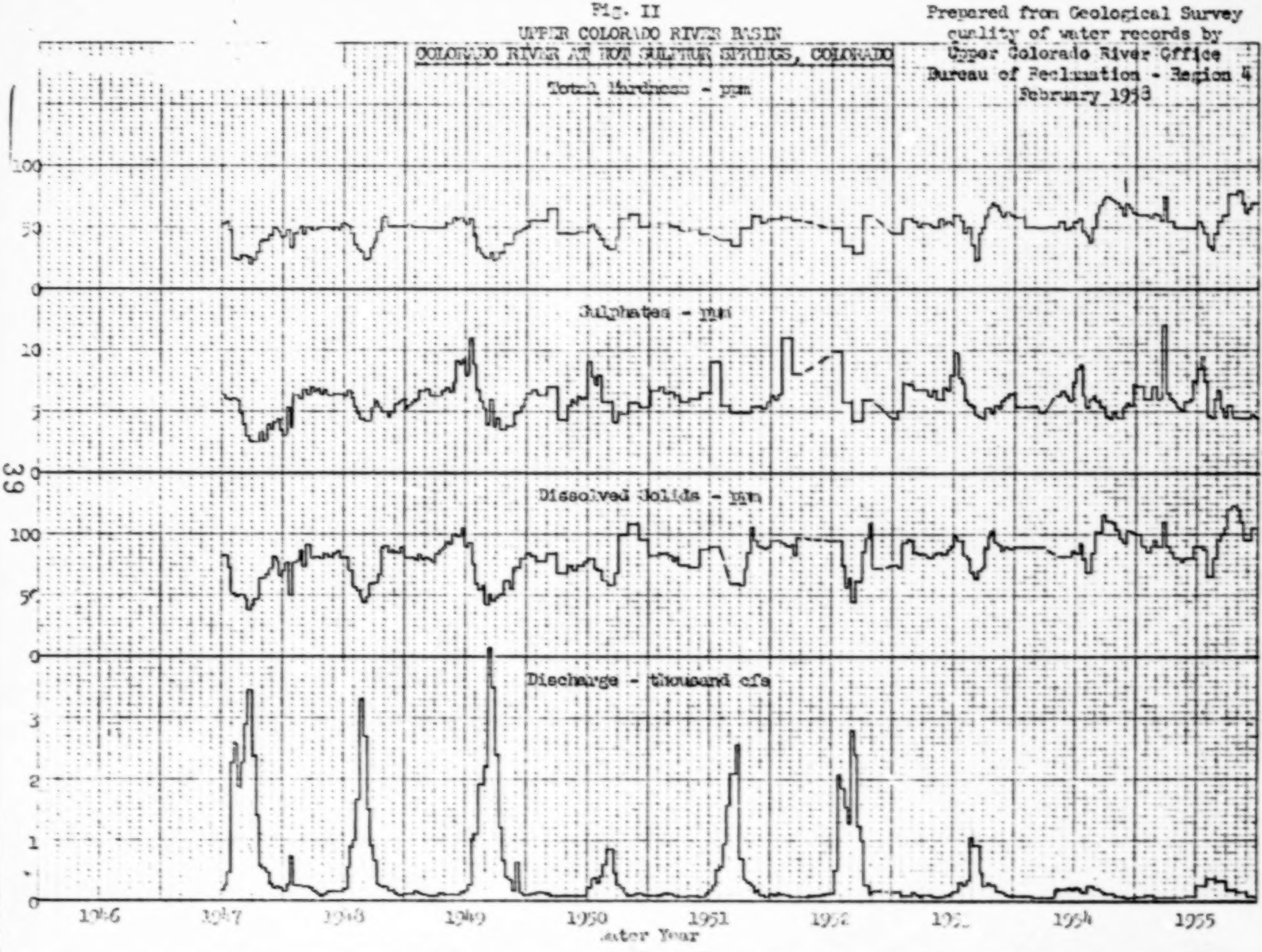

Fig. II
UPPER COLORADO RIVER BASIN
COLORADO RIVER AT HOT SULPHUR SPRINGS, COLORADO

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Figure III

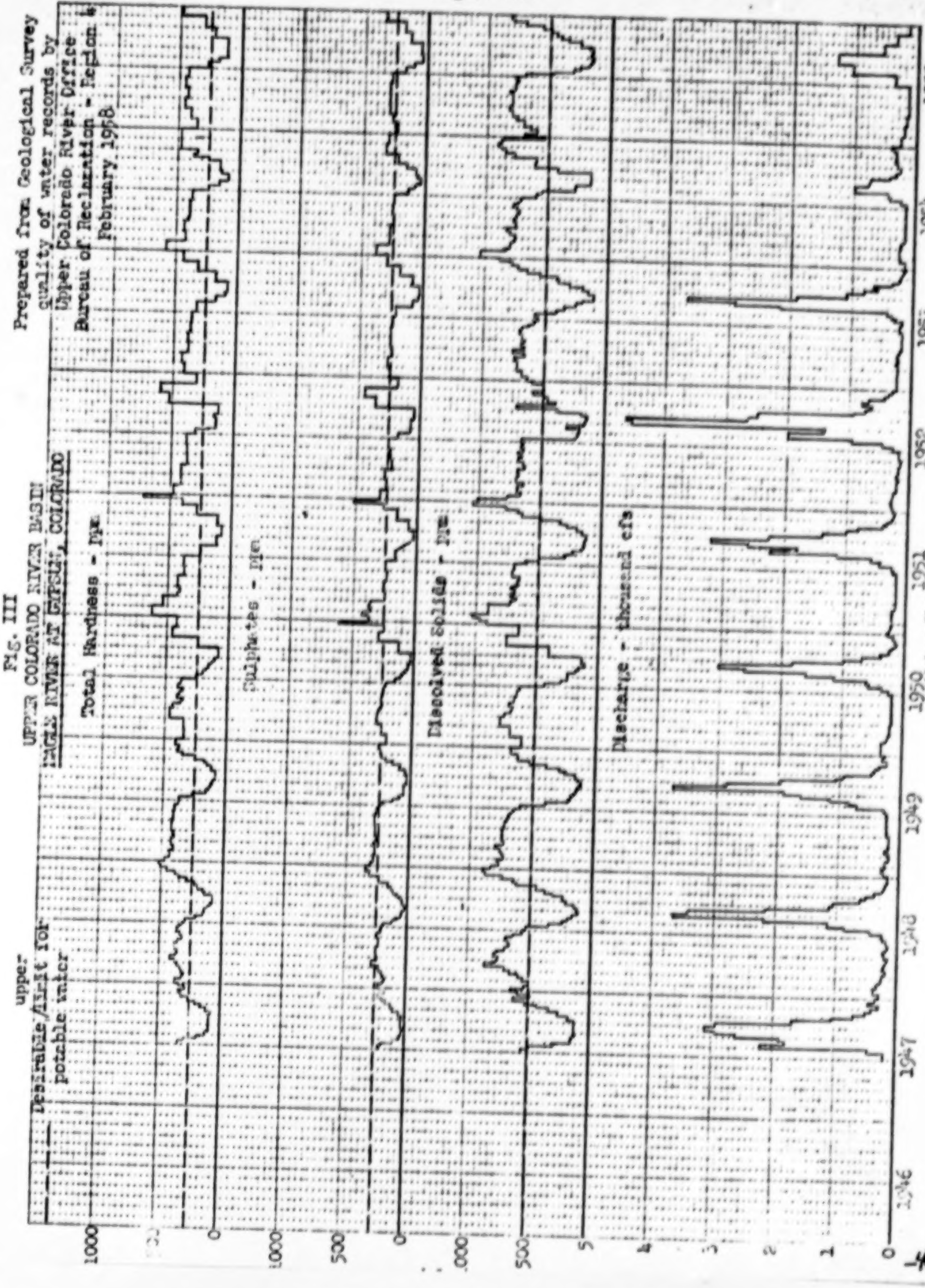

Fig. III
UPPER COLORADO RIVER BASIN
EAGLE RIVER AT GYPSUM, COLORADO

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Figure IV

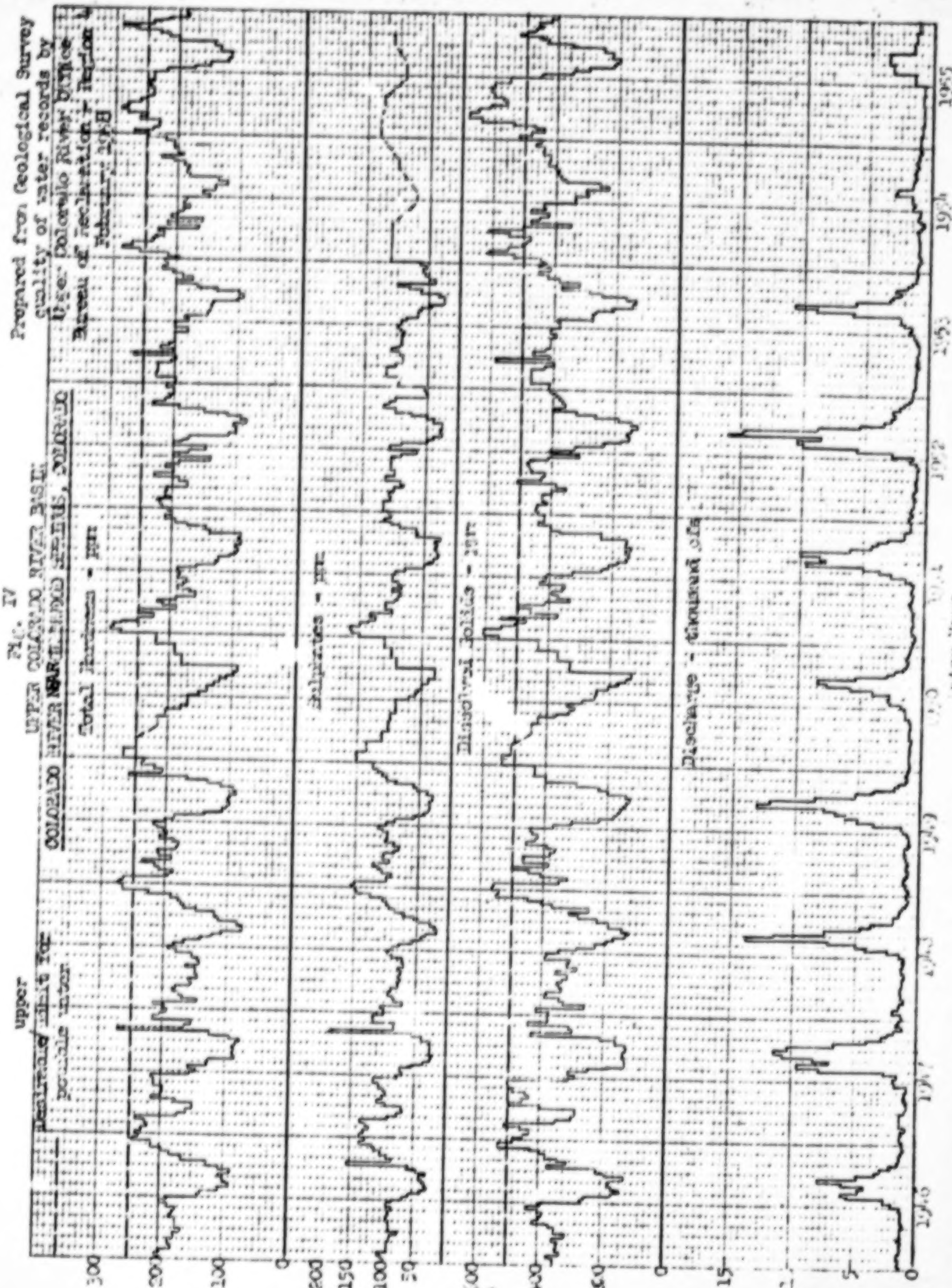
Fig. IV
UPPER COLORADO RIVER BASIN
COLORADO RIVER NEAR GLENWOOD SPRINGS, COLORADO
Upper Desirable limit for potable water
Total Hardness - ppm
Sulphates - ppm
Dissolved Solids - ppm
Discharge - thousand cfs
Prepared from Geological Survey quality of water records by Upper Colorado River Office Bureau of Reclamation - Region 4 February 1958
Water Year
300
200
100
0
200
150
100
50
500
400
300
0
15
10
5
0
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955

Fig. V

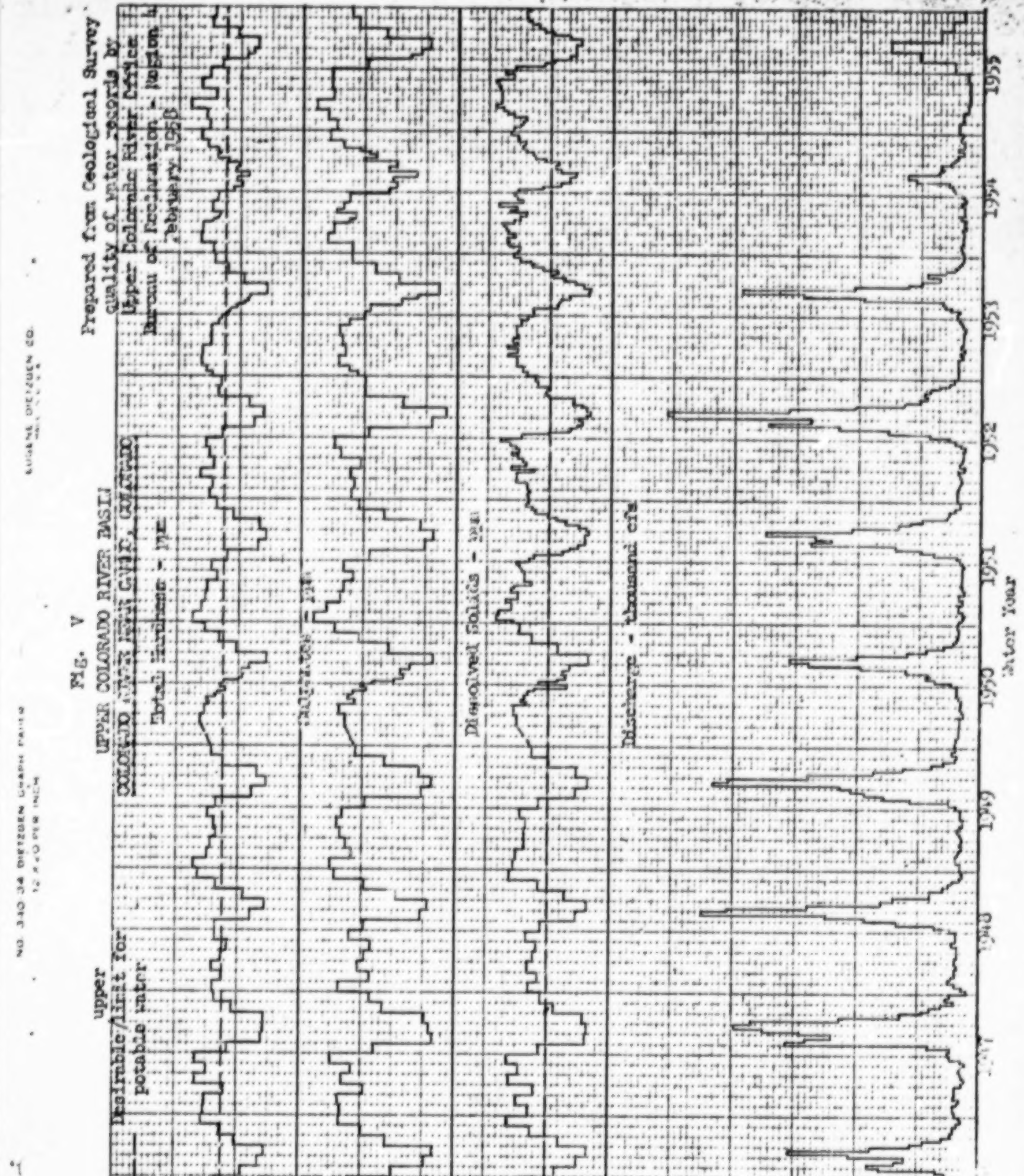
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Fig. V
UPPER COLORADO RIVER BASIN
COLORADO RIVER NEAR CAMEO, COLORADO
Upper
Desirable limit for
potable water
Total Hardness - ppm
Dissolved Solids - ppm
Discharge - thousand cfs
Water Year
Prepared from Geological Survey
quality of water records by
Upper Colorado River Office
Bureau of Reclamation - Region 4
February 1958
300
200
100
0
200
150
100
50
1000
500
0
25
20
15
10
5
0
1947
1948
1949
1950
1951
1952
1953
1954
1955

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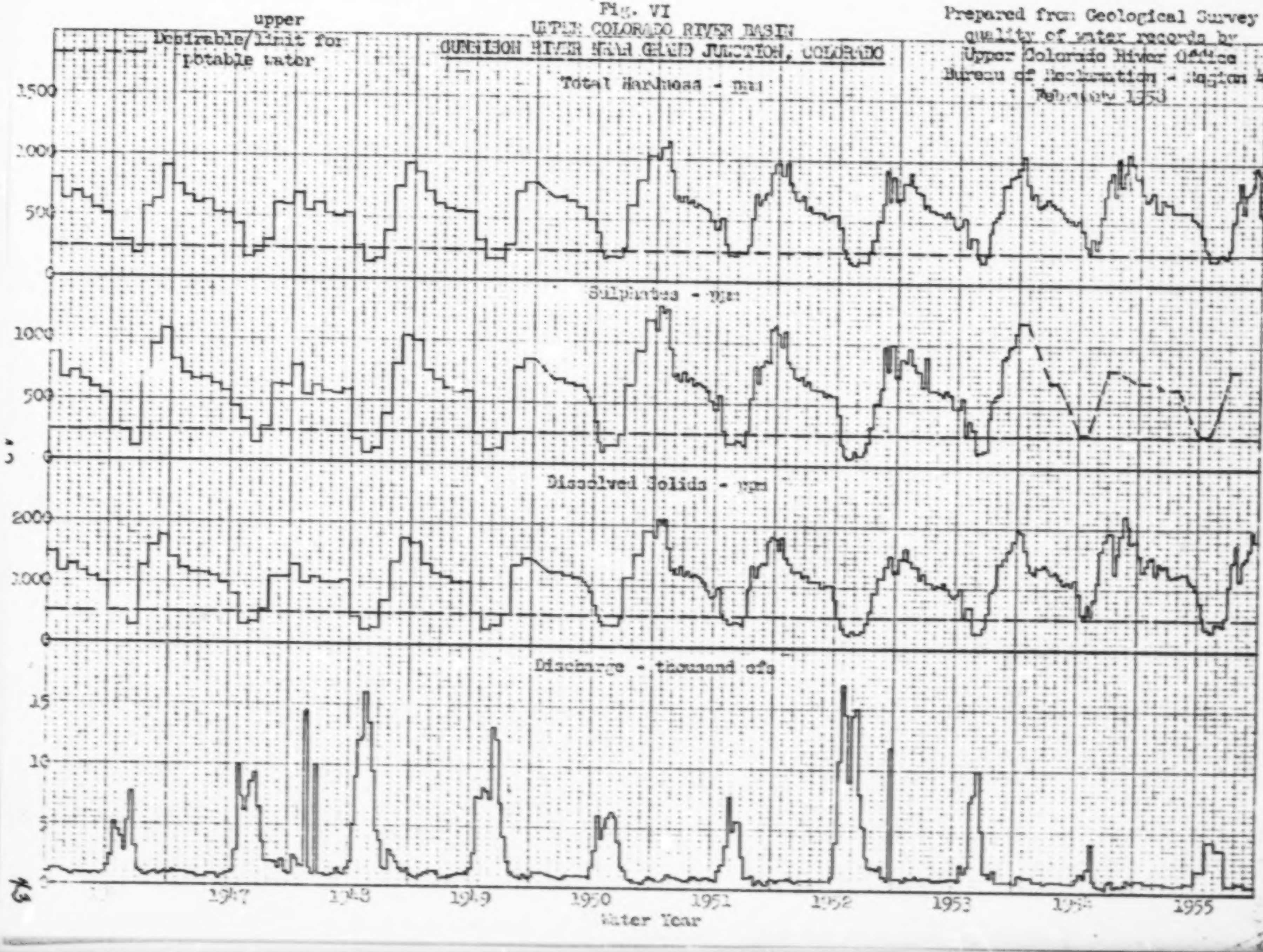

Fig. VI
UPPER COLORADO RIVER BASIN
GUNNISON RIVER NEAR GRAND JUNCTION, COLORADO

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Fig. VI

Fig. VII
UPPER COLORADO RIVER BASIN
DOLORES RIVER NEAR CISCO, UTAH

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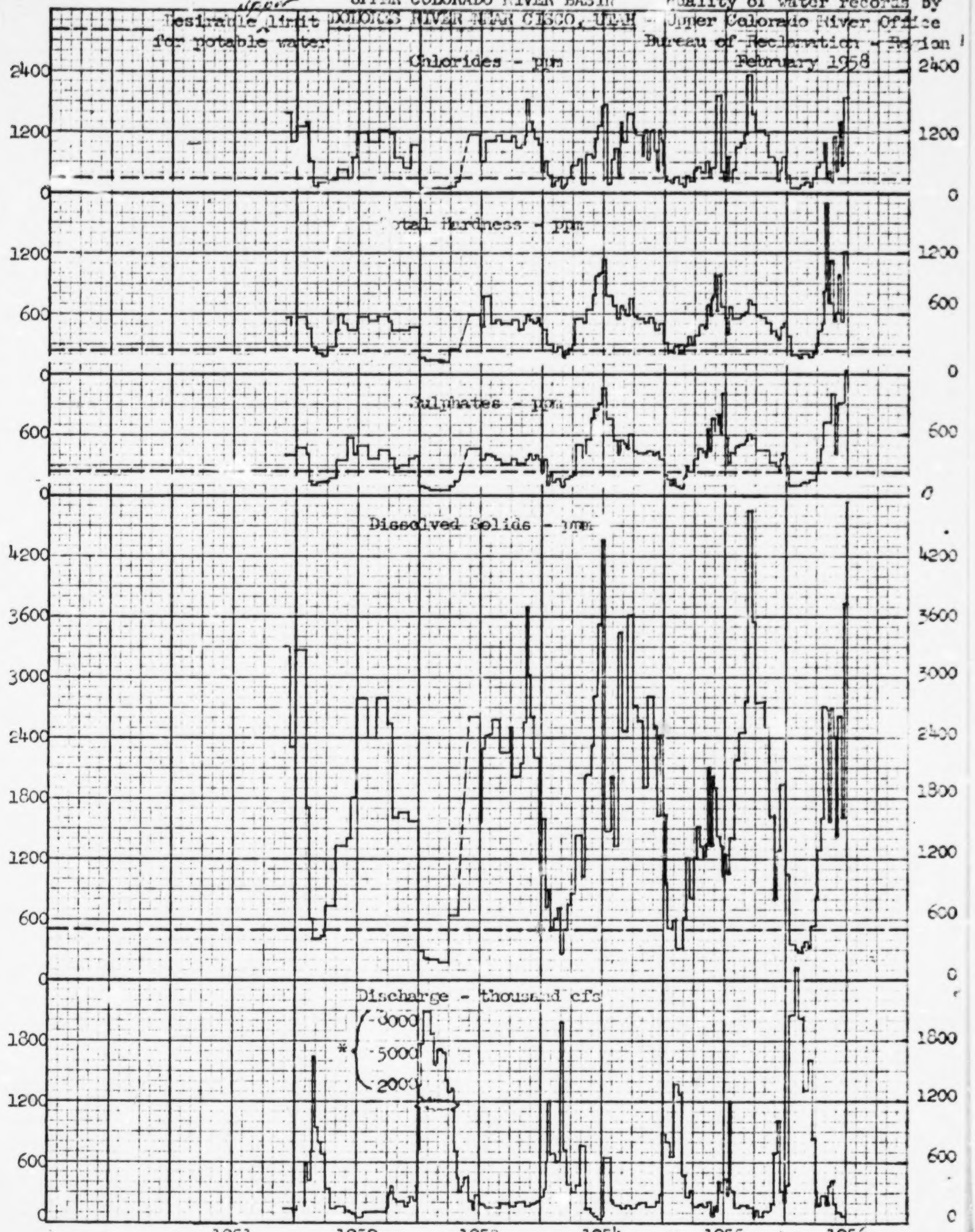

* Aux. scale applies to above 1,000

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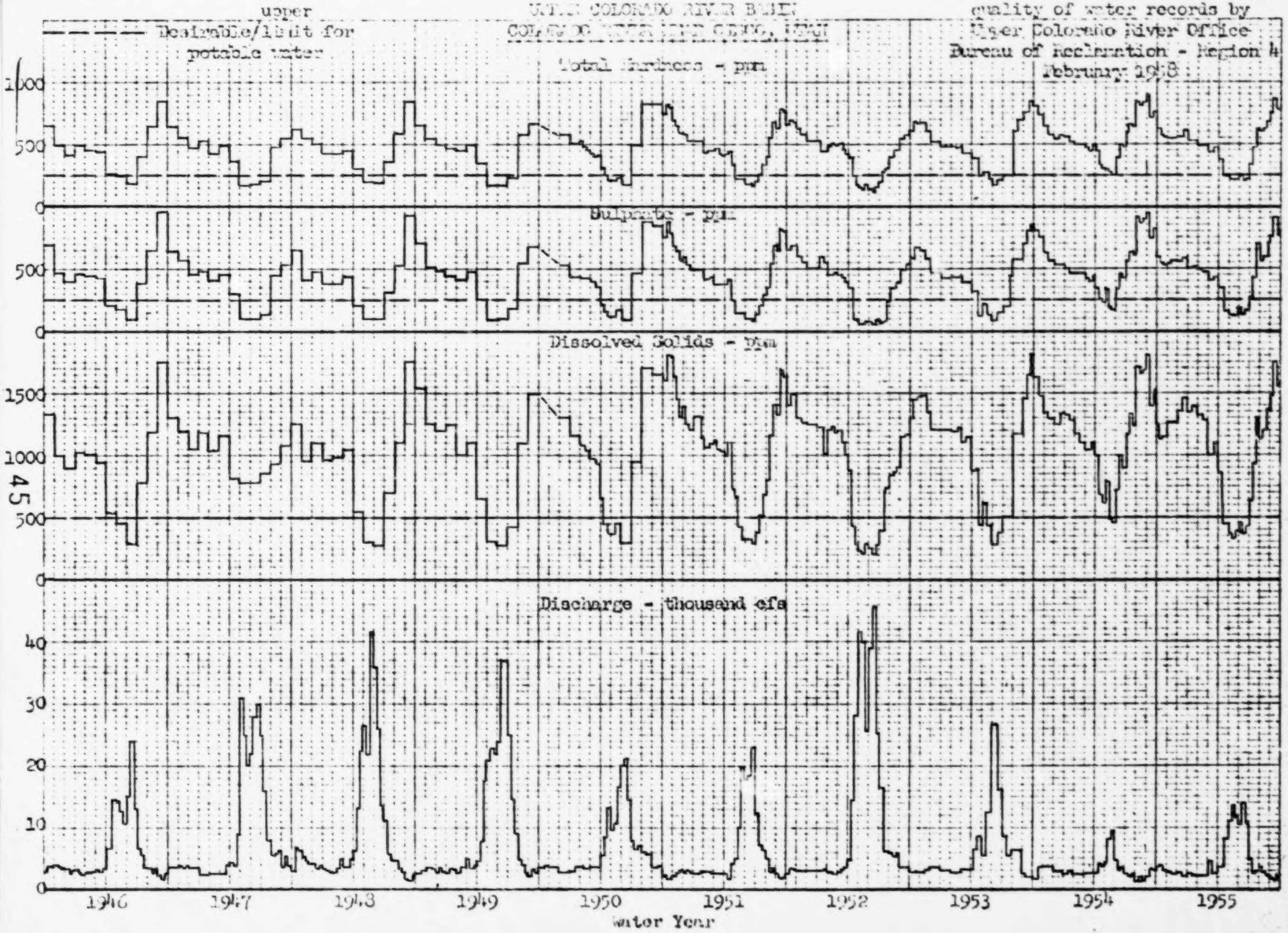
Fig. VIII

FIG. VIII
UPPER COLORADO RIVER BASIN
COLORADO RIVER NEAR CISCO, UTAH



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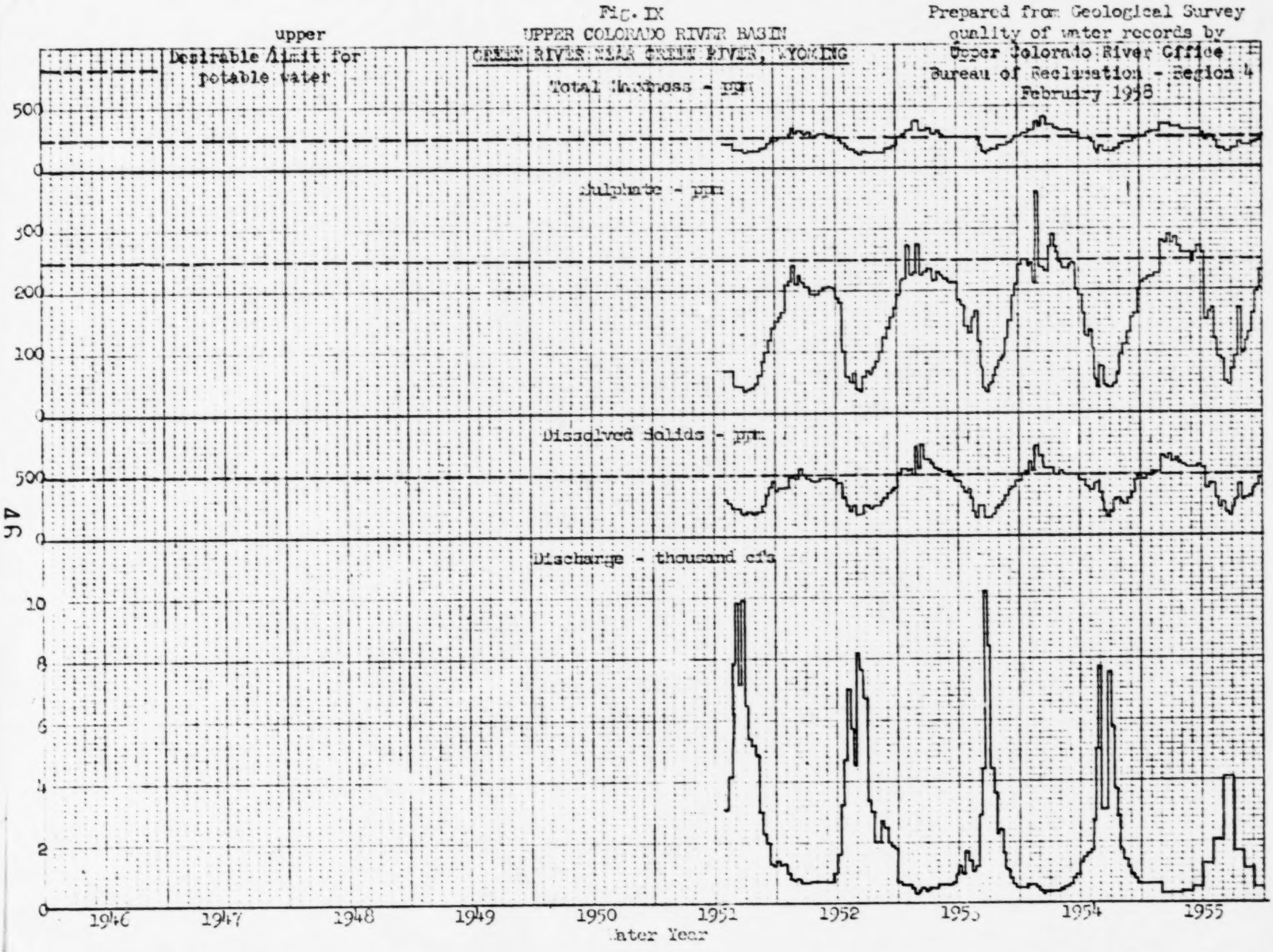

Fig. IX
UPPER COLORADO RIVER BASIN
GREEN RIVER NEAR GREEN RIVER, WYOMING

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Fig. IX

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Fig. X
UPPER COLORADO RIVER BASIN
BLACKS FORK NEAR GREEN RIVER, WYOMING

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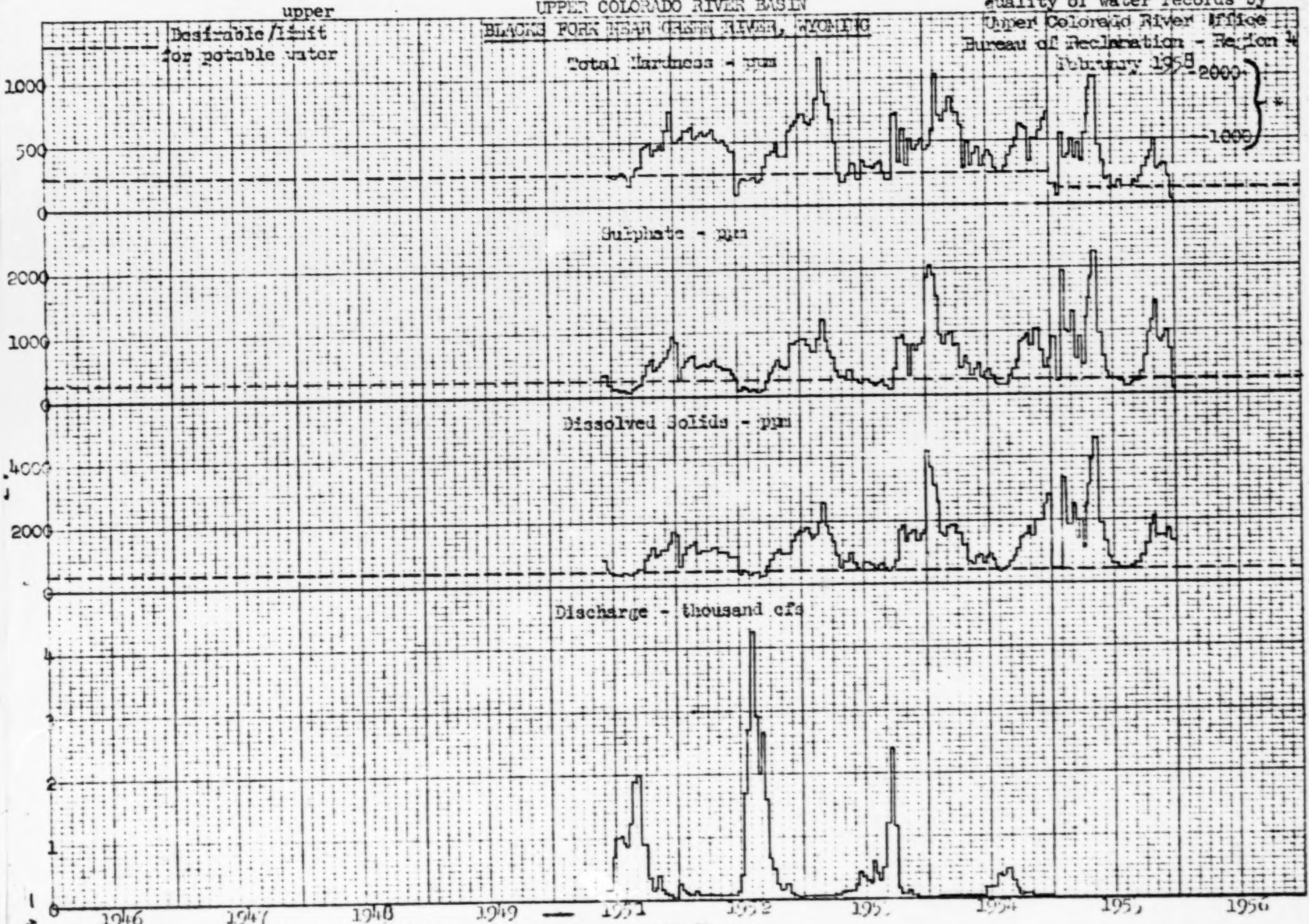

* Aux. scale applies to total hardness
in water year 1955 only.

Fig. X

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Fig. XI

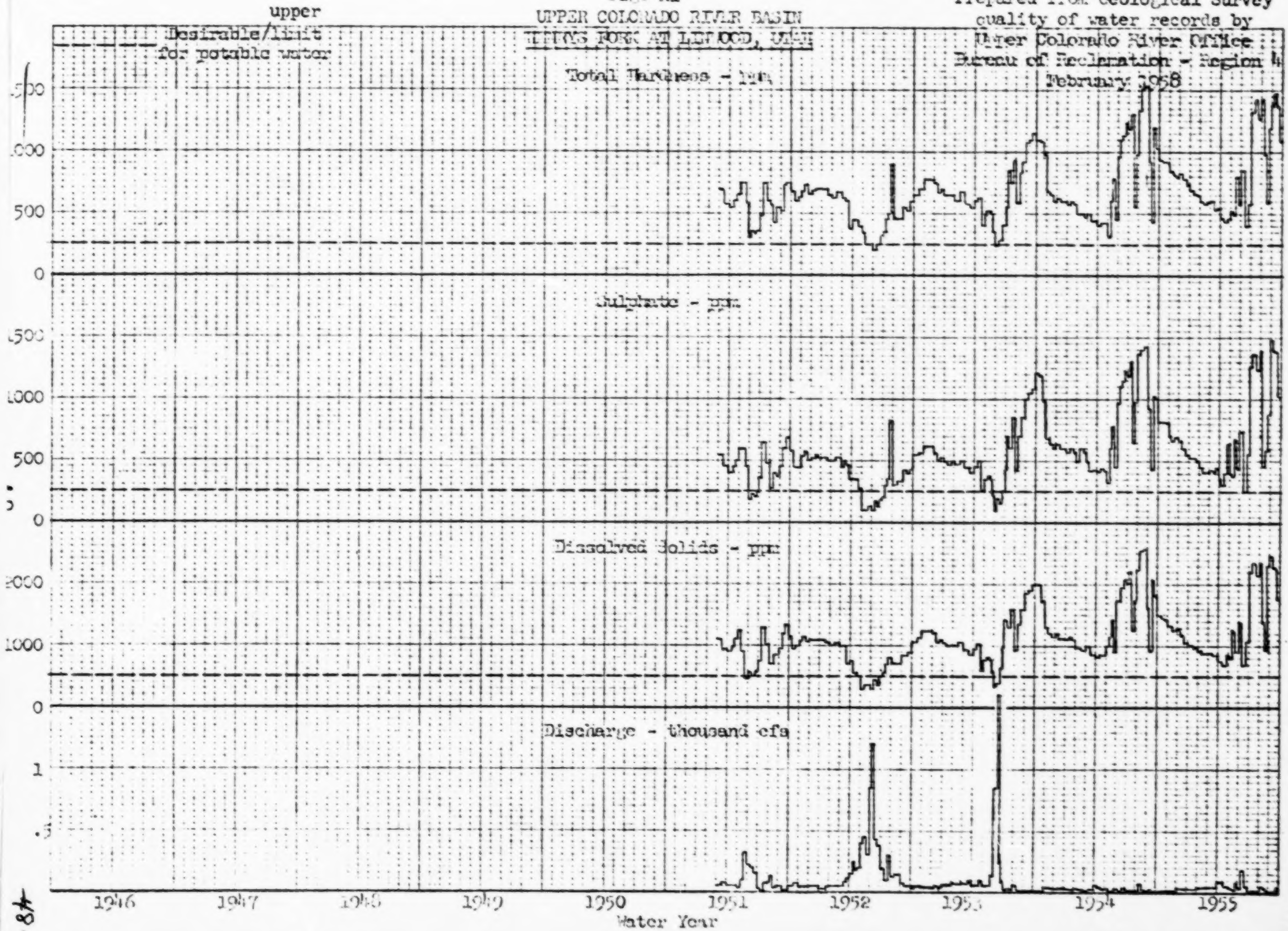

Fig. XI
UPPER COLORADO RIVER BASIN
HENRYS FORK AT LINWOOD, UTAH

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Fig. XII

GREEN RIVER BASIN

YAMPA RIVER NEAR MAYBELL, COLORADO

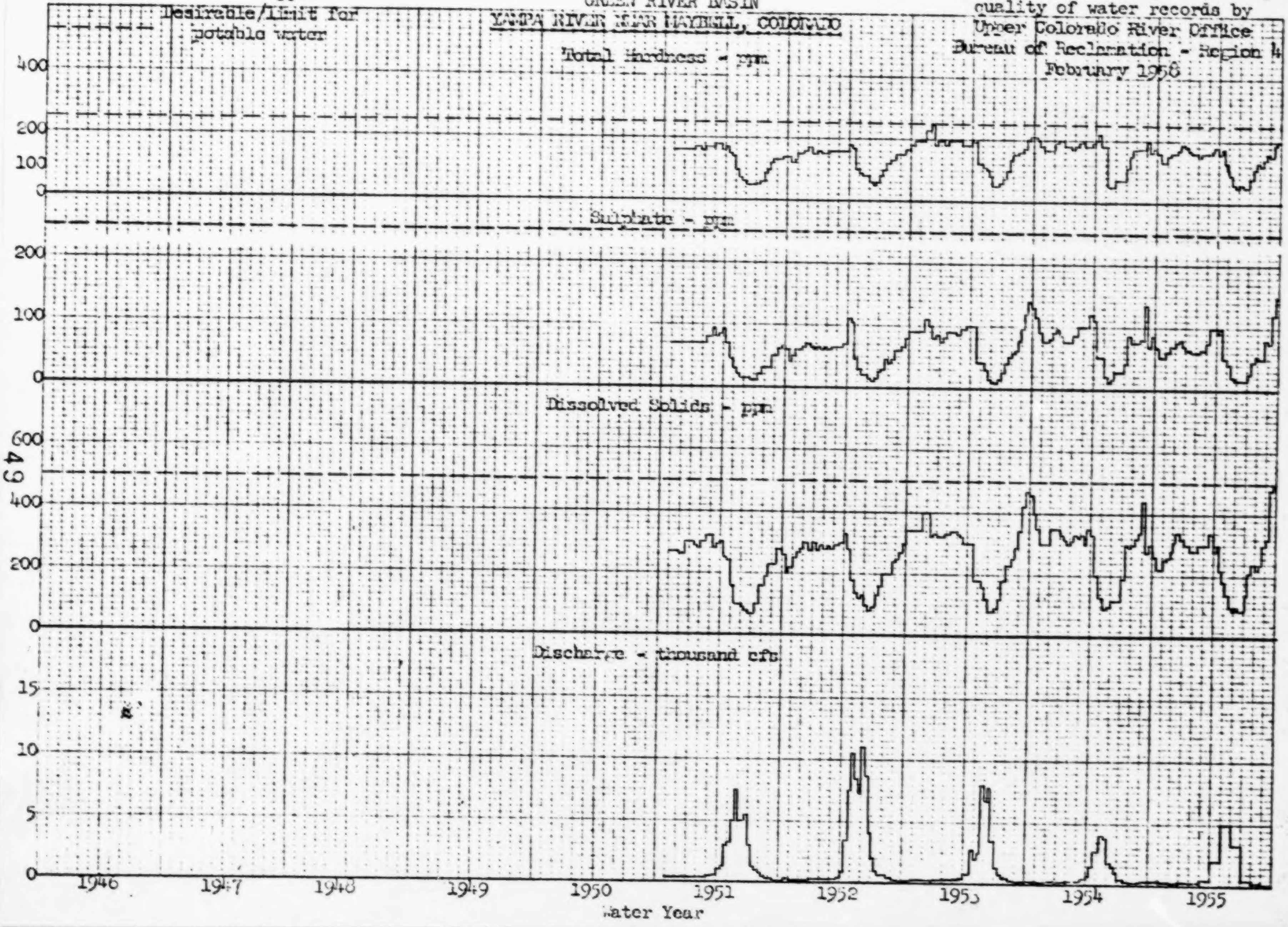

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Fig. XII

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Fig. XIII

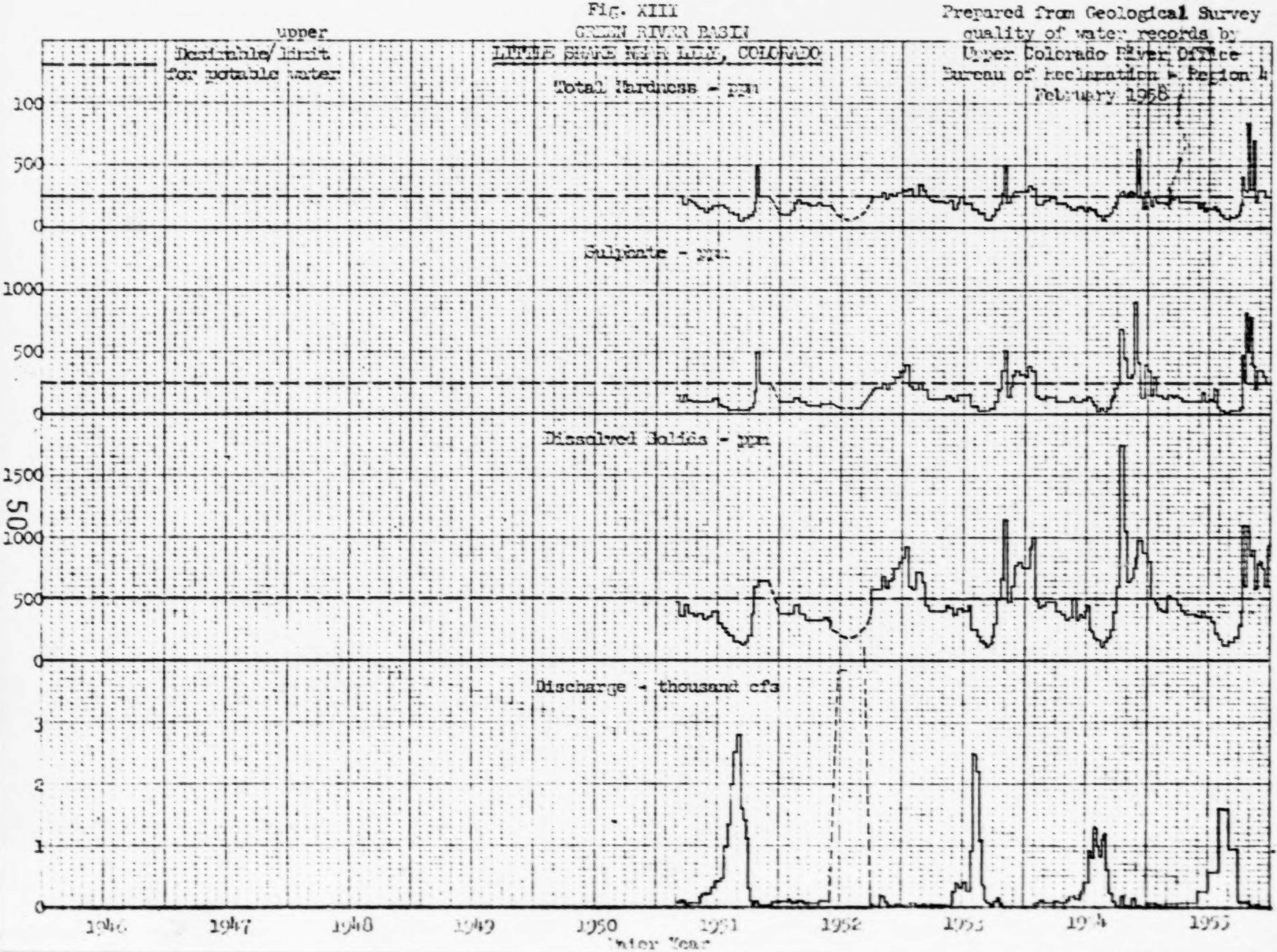

Fig. XIII
GREEN RIVER BASIN
LITTLE SNAKE NEAR LILY, COLORADO

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Fig. XIV

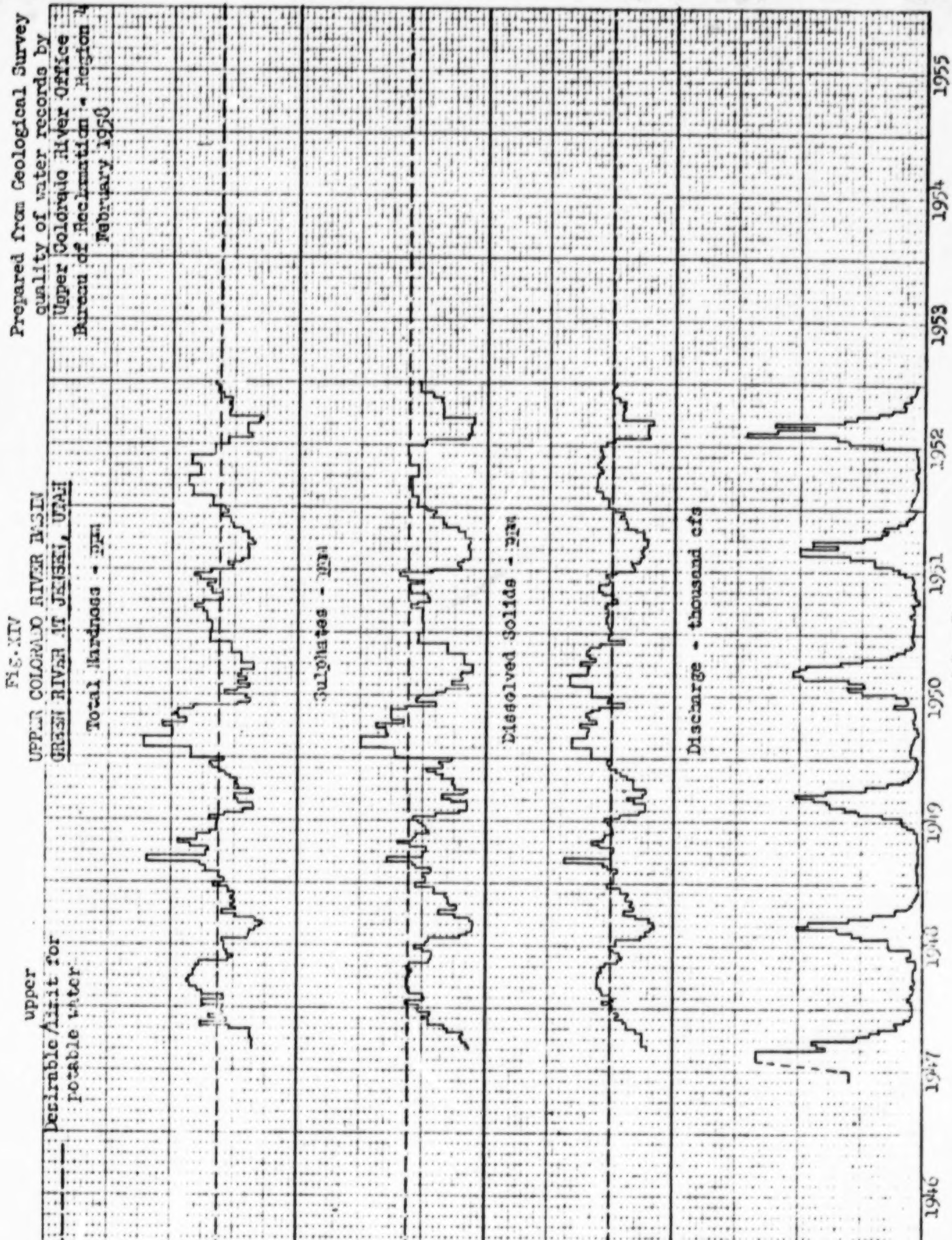

Fig. XIV
UPPER COLORADO RIVER BASIN
GREEN RIVER AT JENSEN, UTAH

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Fig. XV

UPPER COLORADO RIVER BASIN
WHITE RIVER NEAR WATSON, UTAH

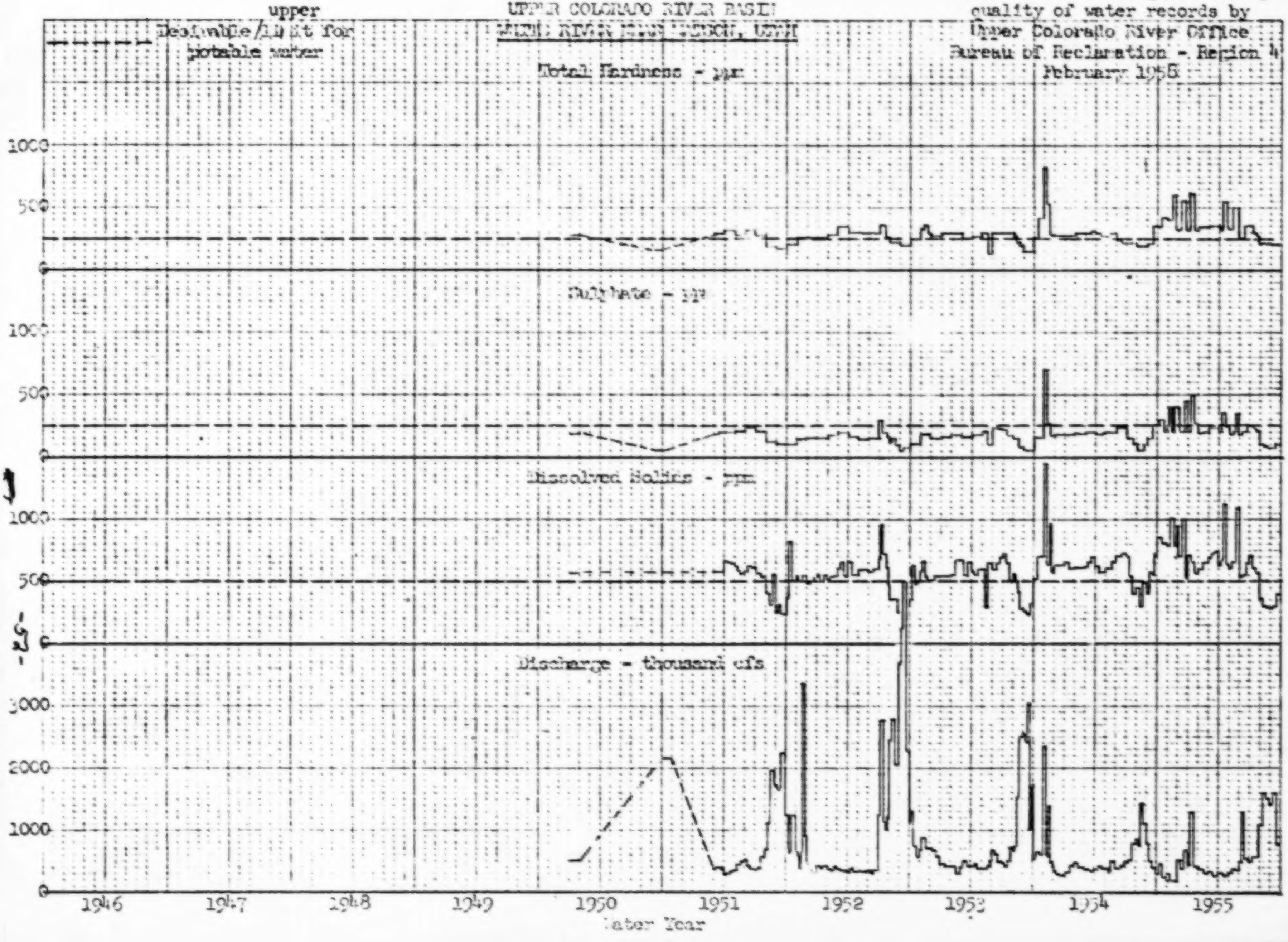

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Fig. XV

Fig. XVI

UPPER COLORADO RIVER BASIN

PRICE RIVER AT WOODSIDE

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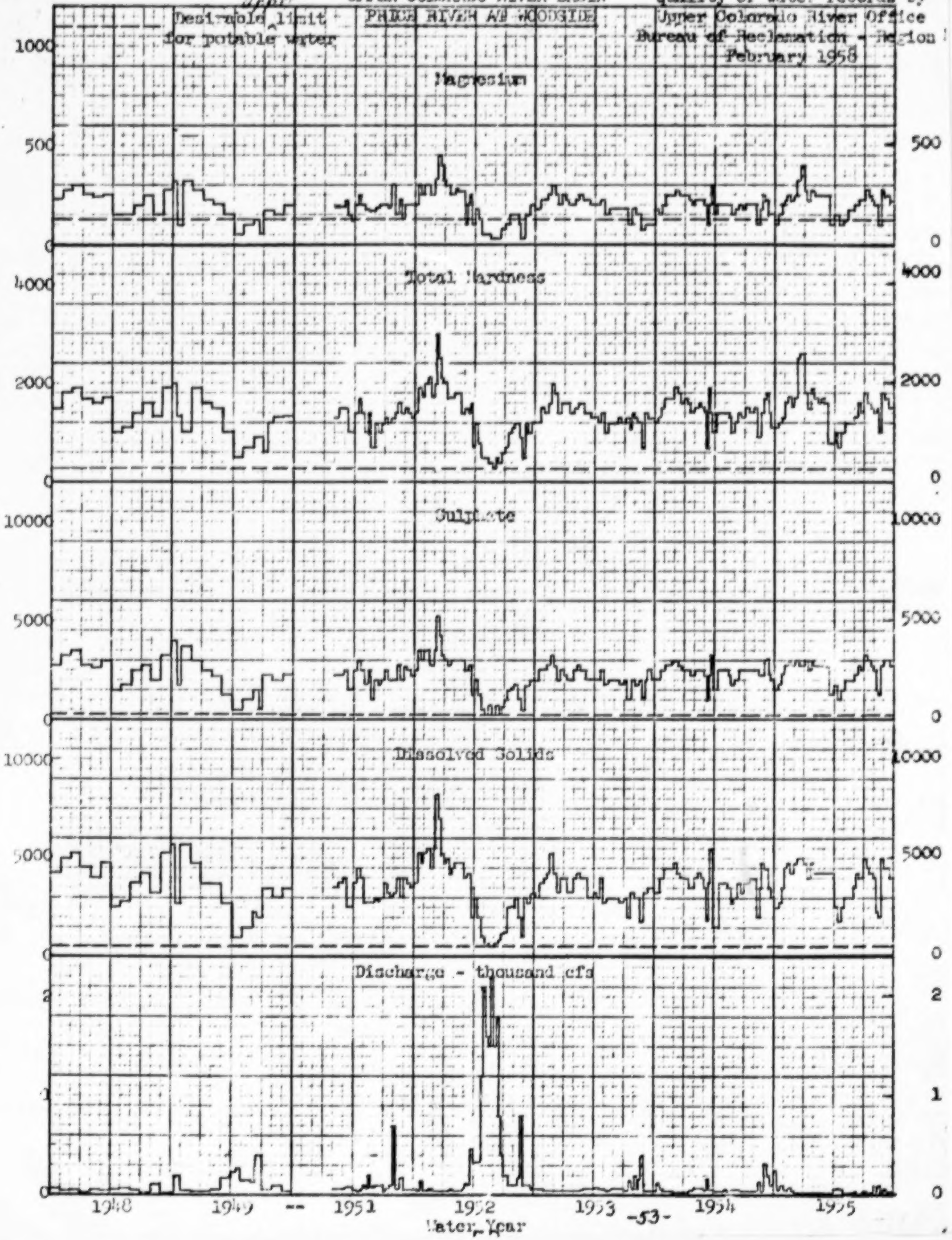

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Fig. XVII

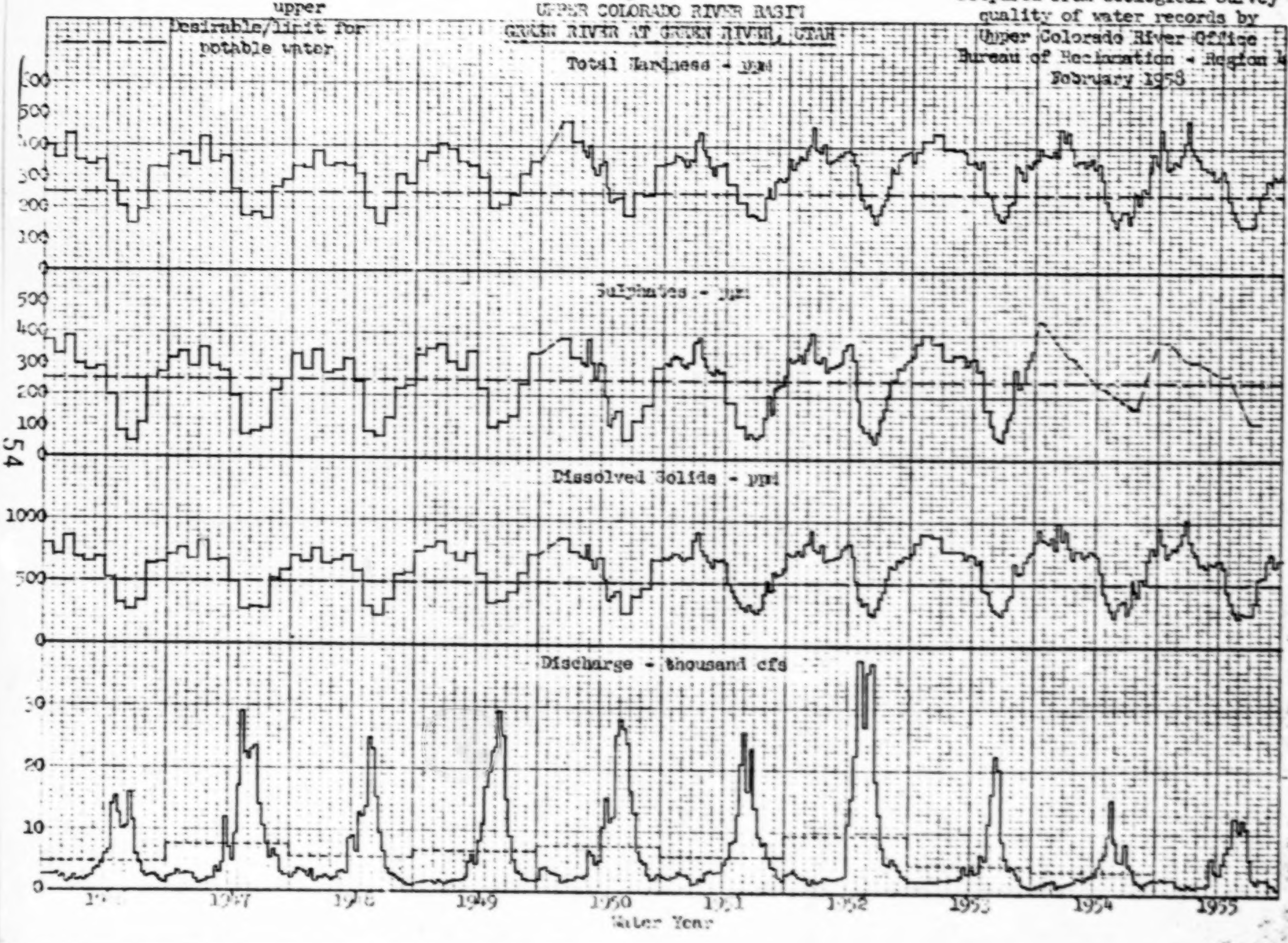

Fig. XVII
UPPER COLORADO RIVER BASIN
GREEN RIVER AT GREEN RIVER, UTAH

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Fig. XVIII
GREEN RIVER BASIN
[illegible] RIVER NEAR GREEN RIVER, UTAH

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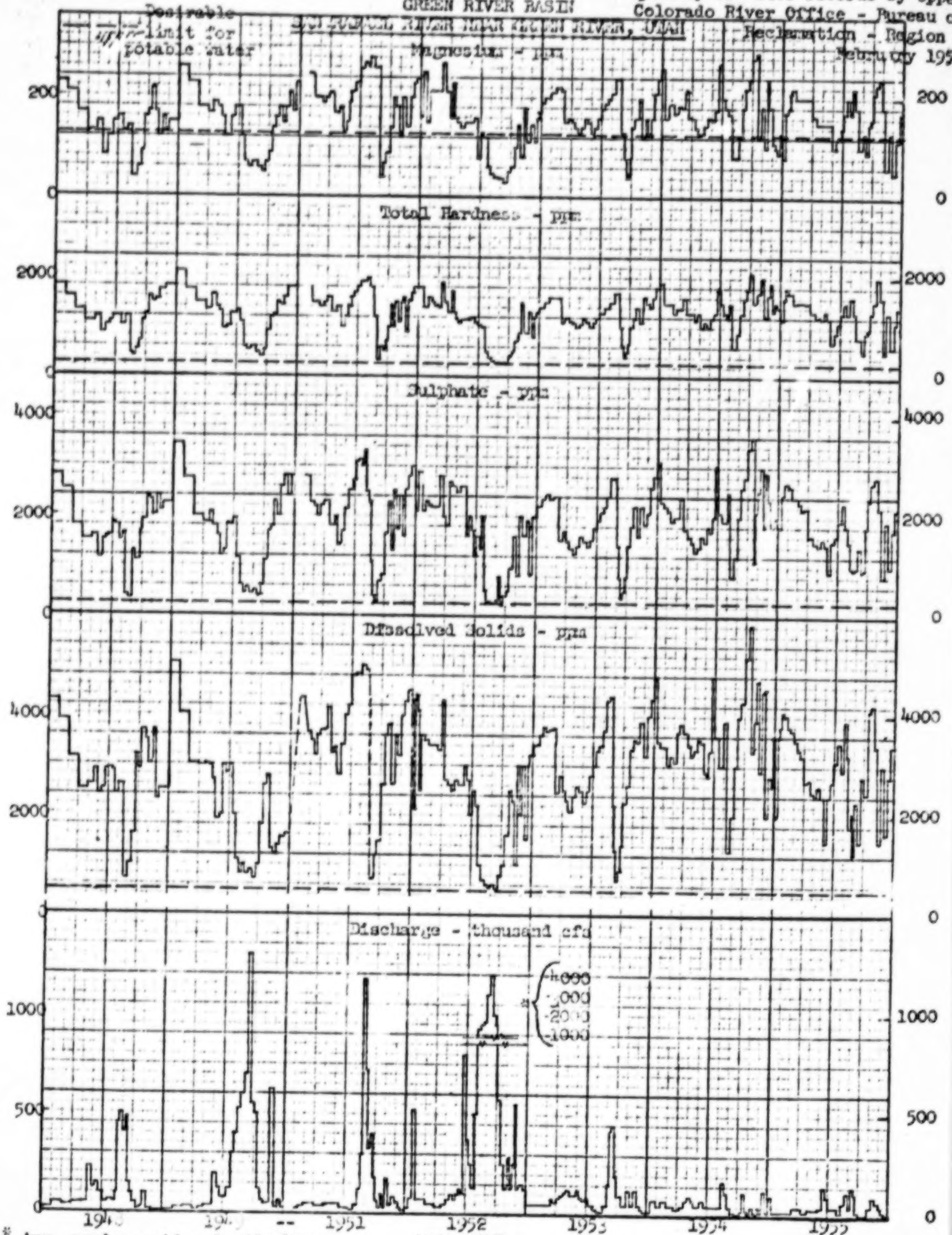

* Aux. scale applies to discharges

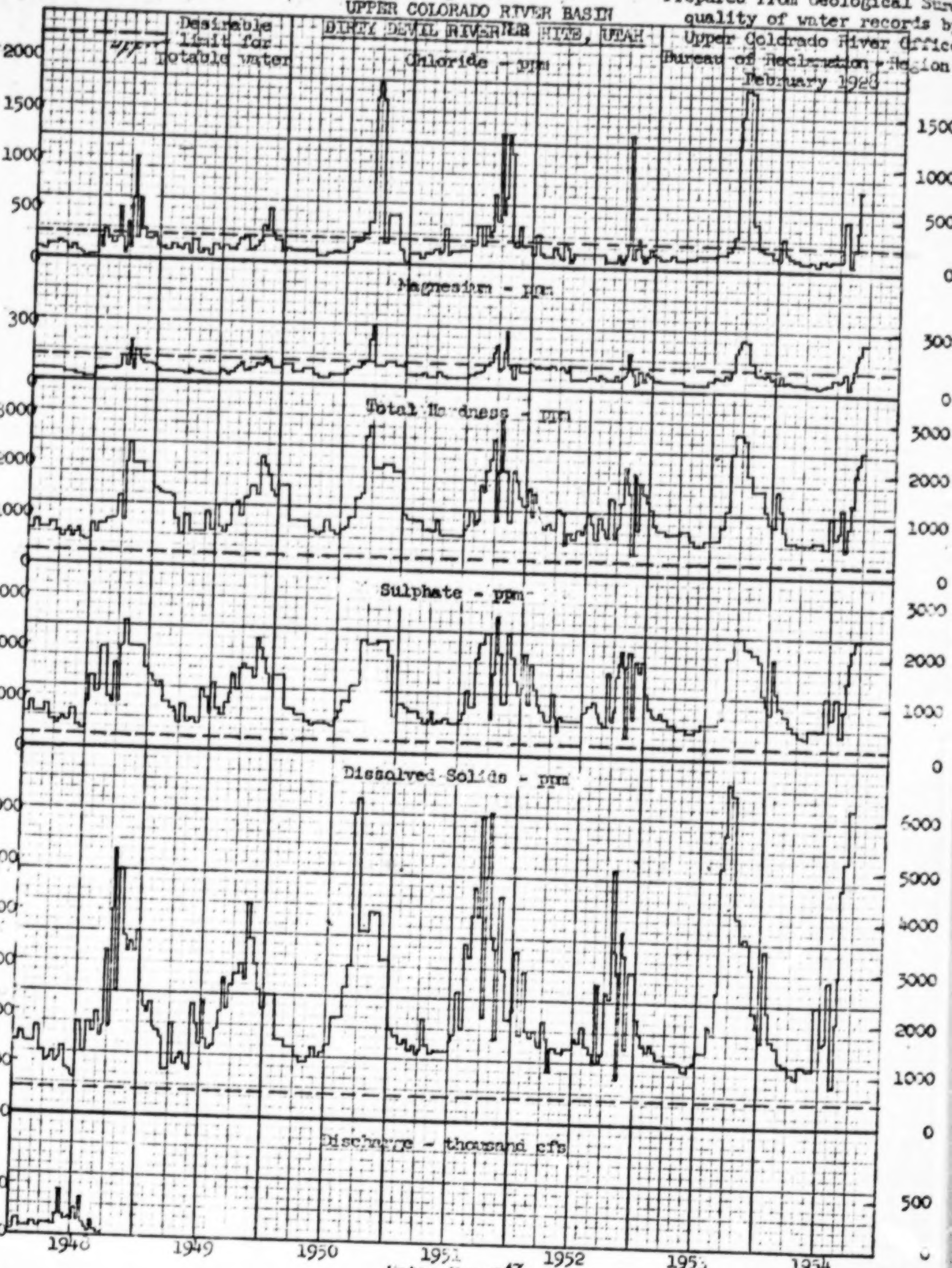

Fig. XIX
UPPER COLORADO RIVER BASIN
DIRTY DEVIL RIVER NEAR HITE, UTAH

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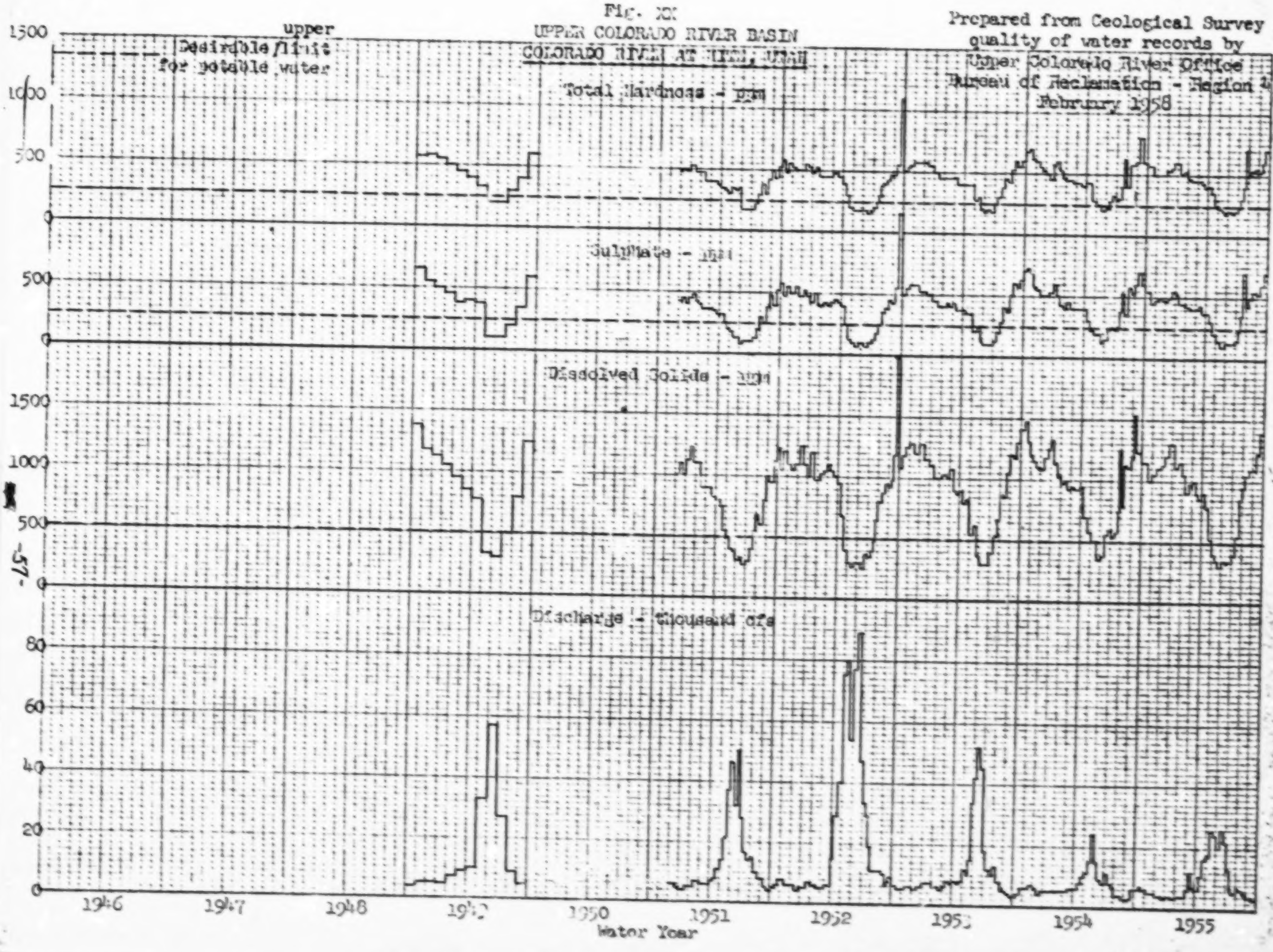
Fig. XX
UPPER COLORADO RIVER BASIN
COLORADO RIVER AT CISCO, UTAH



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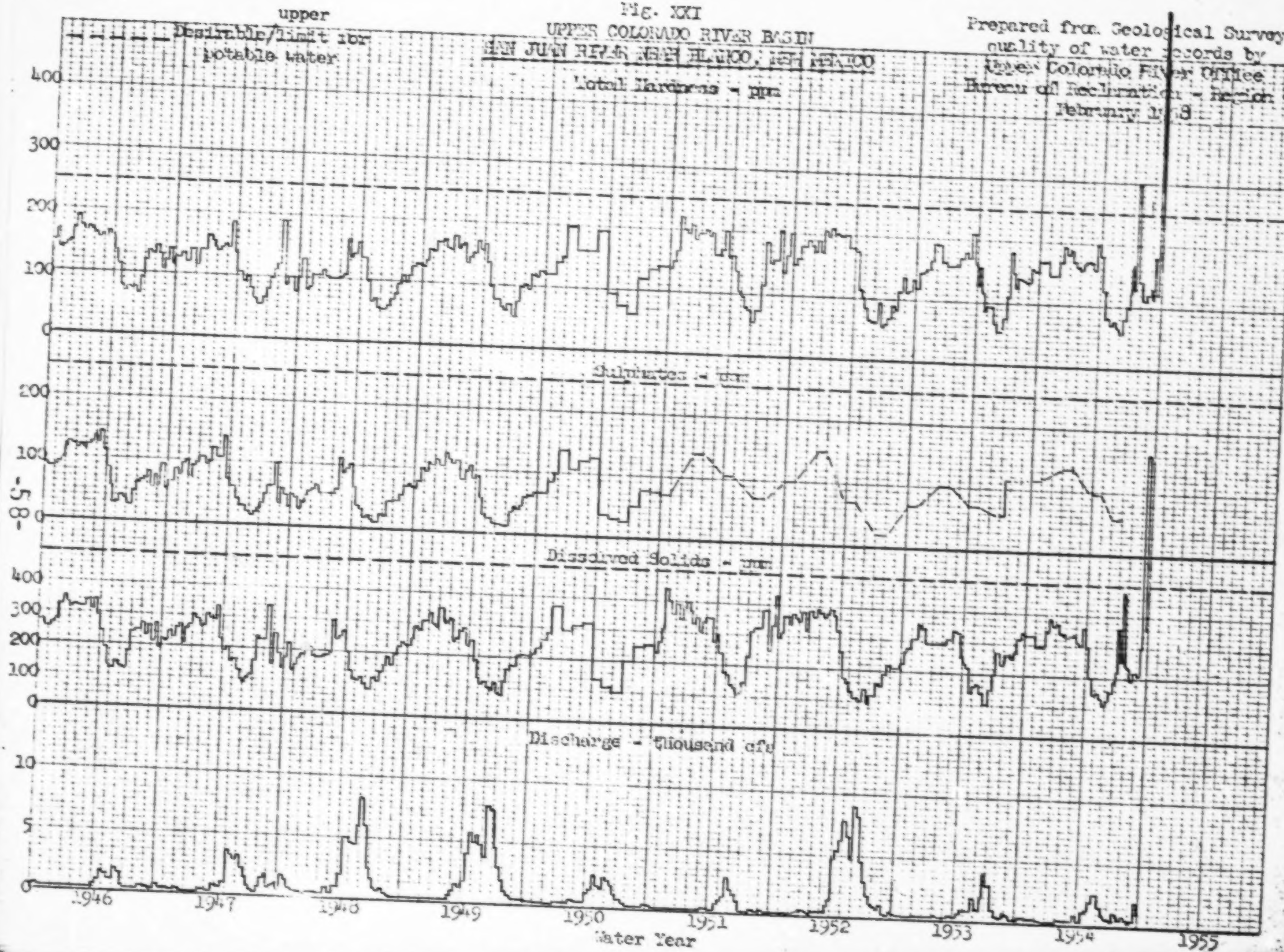

Fig. XXI

UPPER COLORADO RIVER BASIN

SAN JUAN RIVER NEAR BLANCO, NEW MEXICO

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Fig. XXI

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Fig. XXII

UPPER COLORADO RIVER BASIN

ANIMAS RIVER AT FARMINGTON, NEW MEXICO

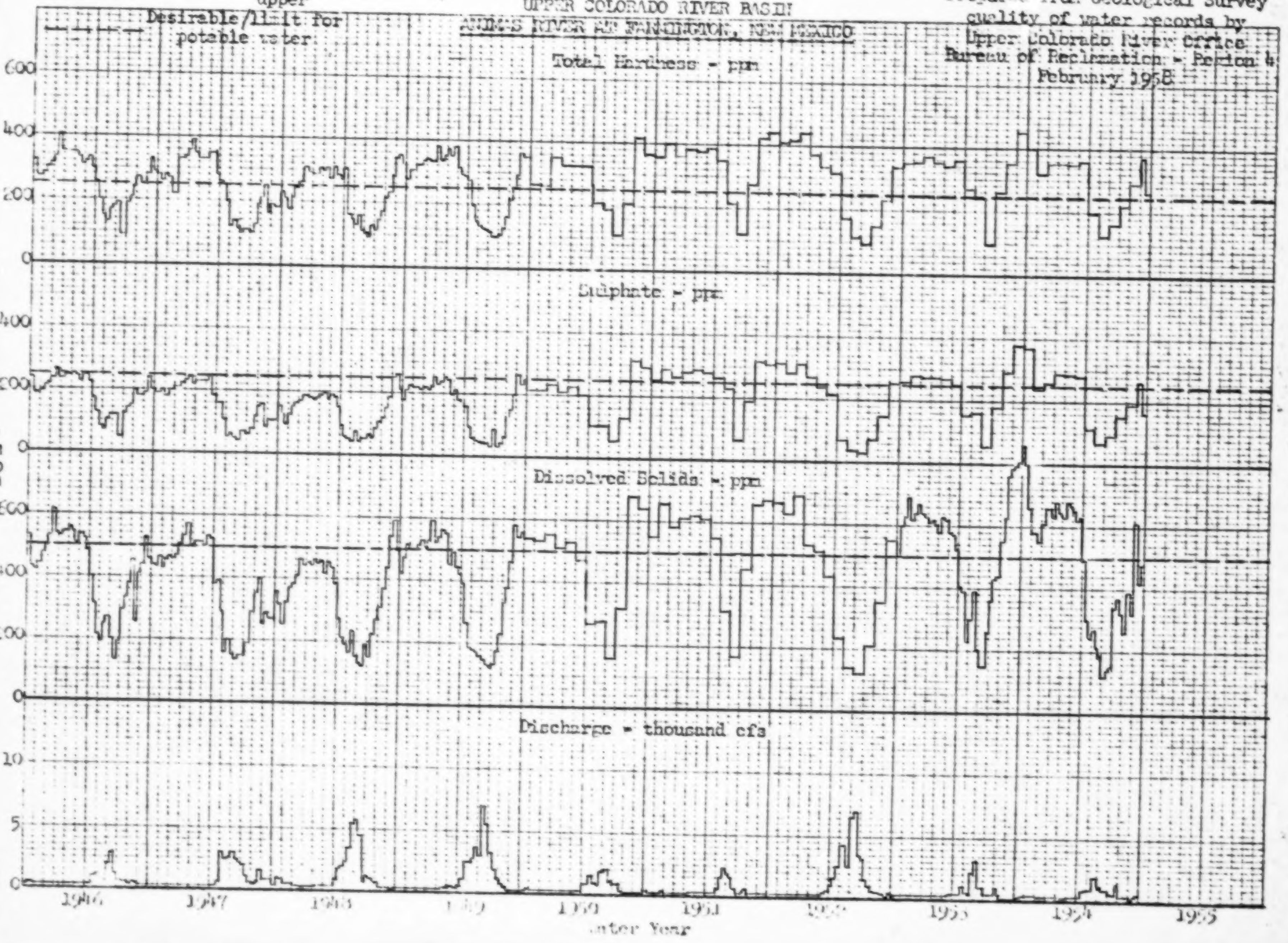

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Fig. XXIII

Fig. XXIII

UPPER COLORADO RIVER BASIN

SAN JUAN RIVER NEAR BLUFF, UTAH

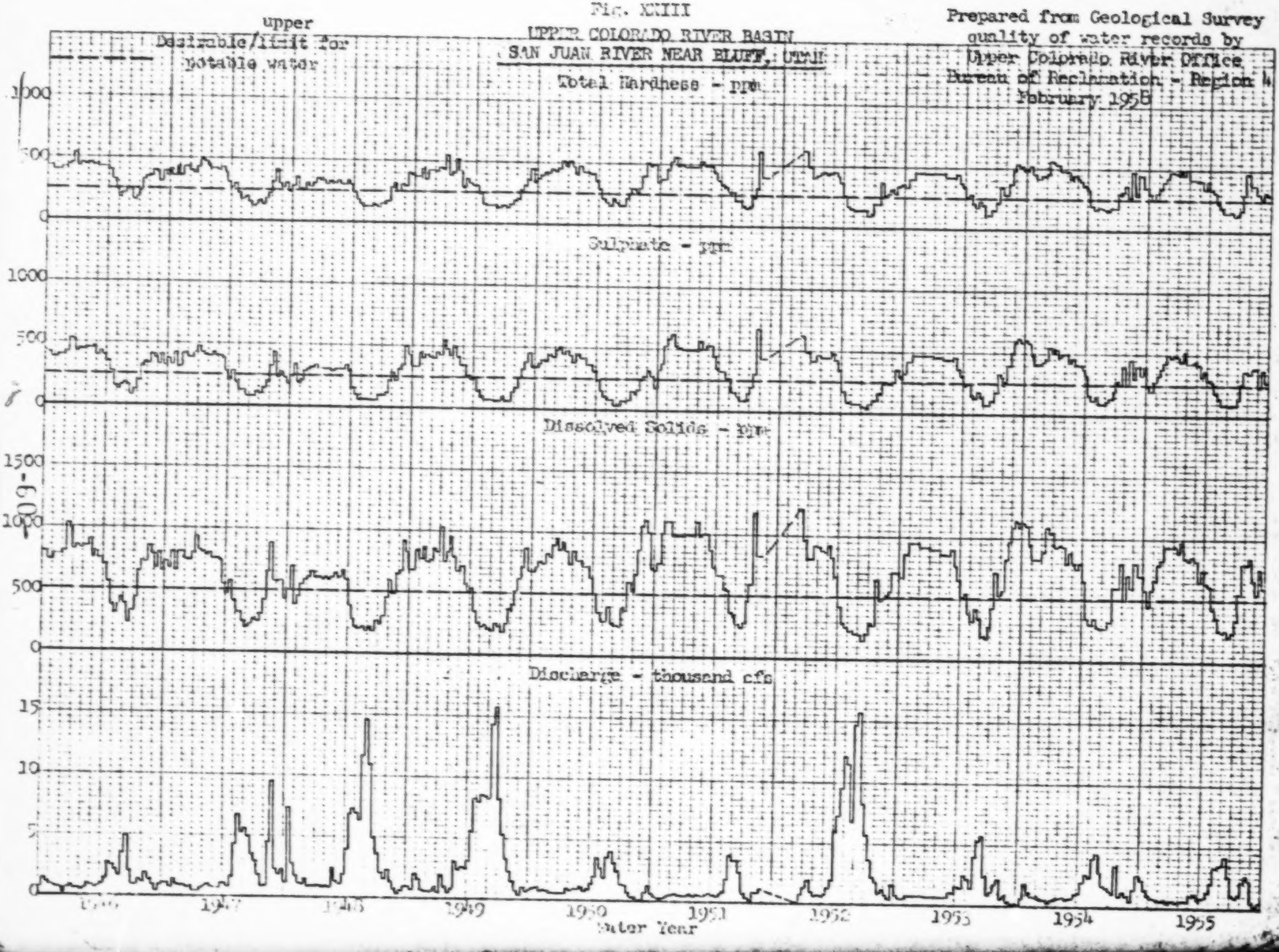

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Fig. XXIV
UPPER COLORADO RIVER BASIN
COLORADO RIVER AT LEES FERRY, ARIZONA

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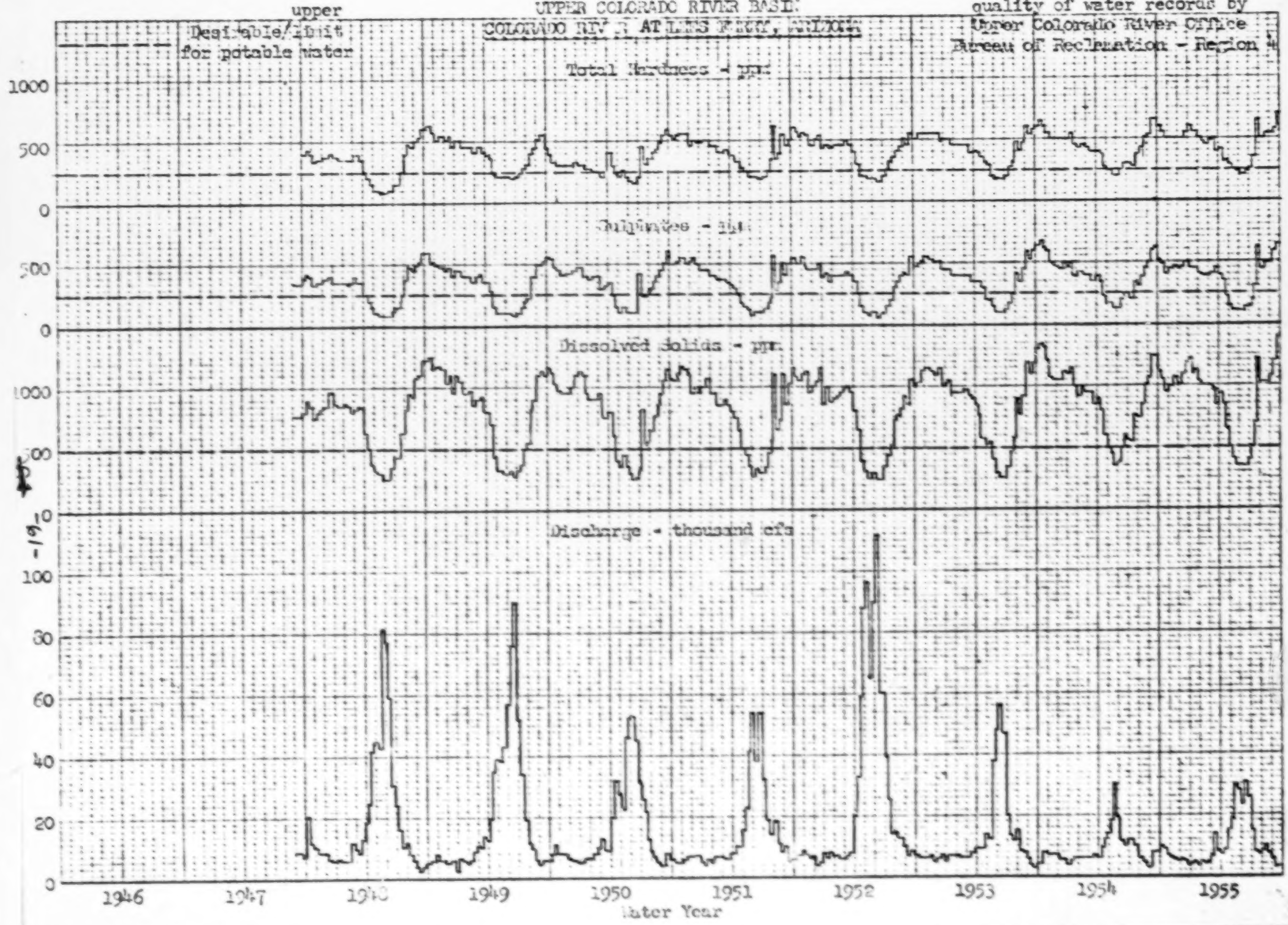

Fig. XXIV